Effects of glass fibres on the filling of polymeric thin ribs

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1 Abstract

This report is the final task of course “42234 Eksperimentel plastteknologi in the 3-week period of June 2007 at DTU, IPL. The report deals with effects of short glass fibers on the replication quality of thin ribbed structures.

The aims of the project work were proposed as:

- Investigate the effects of the glass fibers on the replication of polymeric ribs.

- Investigate fibers orientations based on the injection parameters

- Geometrical size effect on the amount of glass fibers in the post moulded plastic parts.

Several tests were carried and analyzed in order to investigate the three project aims. Mainly test were made on injections moulded parts produced in the first week of the course. From the analysis of the tests conclusions were drawn:

- Fiber reinforced polymers are not well suited for micro structures, due to negative effects of fibers on replication quality.
- PEI as a polymer is much better suited to micro moulding with high tolerances than PS.
- Injection parameters for PEI need to be tailored to fit the specific demands of the micro moulded parts. A compromise between surface quality, and edge sharpness needs to be considered.
- The addition of glass fibers to the injection moulding melt will cause the material to get stiffer (higher modulus of elasticity). The added stiffness affects the materials ability to eject from the mould without creating permanent defects on the specimen.
- The distribution of fibers will vary depending on the geometry of the moulded parts.

2 Acknowledgments

The authors of this report would like to take the opportunity to make a special thank Aminul Islam Mohammed the course supervisor, for advices and help given in private corresponding and discussions, pursuant to carrying out the experiments, analyzing the results, and writing the report.

We would also like to thank Torben Tang and Katja Jankova for assistance and advice in relation to our chemical experiments.

3 Table of content

4 Introduction

In resent years micro injection moulding have been, and still is a growing industry. The need for micro parts in industrial products is on a rise, and the demand for tailor-made materials with specific parameters becomes larger.

Injection moulding offers a mean for low cost, mass fabrication ability with high dimensional accuracy, and good part quality, and is therefore well suited to production of micro parts.

On larger scale, polymeric materials have been widely used for mass productions with injection moulding. The reason that plastic is preferred as a material is due to: easy formability, light weight, resistance to various chemicals, low electric conductivity, ability to be transparent and colored, and low cost.

Other reasons why polymers are a good candidates for micro injection moulding, is that the material properties can easily be tailored. The most common way of strengthening polymers for injection moulding is to add fibers to the mix. Fibers, typically being from glass fiber are usually distinguished between short (0,5-1mm) fibers, and long 10-15mm. The length, distribution, amount and type of fibers together determine the materials strength. In larger injection moulded parts with low tolerances and fiber reinforced plastic, usually filling is not a problem. However for smaller parts with thin geometry the addition of fibers to the mix can cause problems with correct filling of the mould.

Injection moulding setting affect the replication quality and amount of mould defects on moulded parts. Due to this face a need for optimizing injection parameters as well as polymers + fiber mix exists, and will be further investigated in this report.

5 Project definition

This report is the work of three students undertaking the course “42234 - Eksperimentel plastteknologi” in the 3-week period of June 2007.

The aim of the project work has been described at the introduction of the course:

a. Investigate the effects of the glass fibers on the replication of polymeric ribs.

b. Investigate fibers orientations based on the injection parameters

c. Geometrical size effect on the amount of glass fibers in the post moulded plastic parts.

6 Materials used

The following materials were used in the investigation.

6.1 Polystyrene (PS)

Polystyrene is an inexpensive amorphous thermo plastic that is vitreous, brittle and has low strength. However it is also hard and stiff. Foamed PS is used for packaging and insulation purposes. The structural formula of polystyrene is shown on Figure 1:

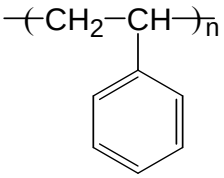


Figure 1

Polystyrene is not weather resistant, and therefore not suitable for outdoor use.

Basic PS is transparent (it transmits about 90% of the sunlight) and has unlimited dyeing possibilities. Assembly can be done with gluing.

6.2 PolyetherImid (PEI)

PolyetherImid is a transparent high performance polymer. It has high strength and rigidity at elevated temperatures, and long term heat resistance. PEI has excellent dimensional stability combined with broad chemical resistance and it has outstanding thermal, mechanical and electrical properties compared to traditional polymers.
PEI is well suited for injection moulding. It is used in the medical, food and automotive industry. And in aircraft aerospace and vacuum technologies, the most common product is microwave dishes, surgical equipment and connectors.

The structural formula of polystyrene is shown on Figure 2:

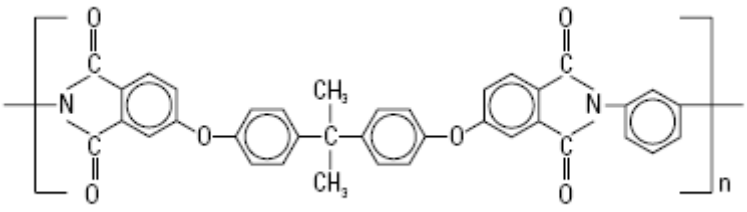


Figure 2

6.3 Plastic composites

Composites are the combination of two or more materials that are essentially insoluble in each other. The basic substance or binder material is often referred to as the matrix material. The additional materials are either additives or reinforcement substances.

The properties and the structural performance of the composite material are superior to those of the constituents acting independently. Composites are usually characterized by relatively high strength and stiffness.

A common way mixing composites is by adding reinforcement fiber materials to the plastics in order to improve their mechanical properties and to reduce cost when compared to the materials of similar strength. By adding glass, carbon, aramide and boride-fibers to the matrix, superior properties including tensile strength, hardness, toughness, impact strength, and dimensional stability of plastics can be achieved..

Mechanical properties of the composites obtained from plastics and fibers can vary depending on the fiber distribution in the structure, fiber size, fiber fraction and fiber–plastic adhesion force. To affect a high adhesion force between the plastic and fiber, these are usually coated with materials having less surface energy like e.g. silane.

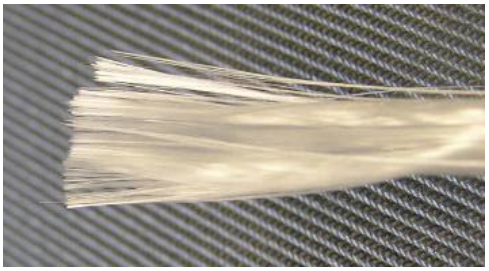
Although all thermoplastics can be reinforced with fibers, Nylon (PA6), polypropylene, polystyrene, ABS and SAN are the most widely used fiber reinforced materials in the industry.

6.4 Glass Fibers

Glass fibers are made of silicon oxide with addition of small amounts of other oxides. Glass fibers are extensively used due to their high strength, good temperature and corrosion resistance, and low price compared to other additive fiber materials.

There are two main types of glass fibers: E-glass and S-glass. The first type is the most used, and takes its name from its good electrical properties. The second type is very strong (S-glass), stiff, and temperature resistant.

Glass fibers are used as reinforcing materials in many sectors, e.g. automotive and naval industries, sport equipment etc, and they are produced by a spinning process, in which they are pulled out through a nozzle from molten glass at a speed of thousands of meter/min.



Picture 1 - Batch of long glass fibers

7 Injection Moulding (working principle)

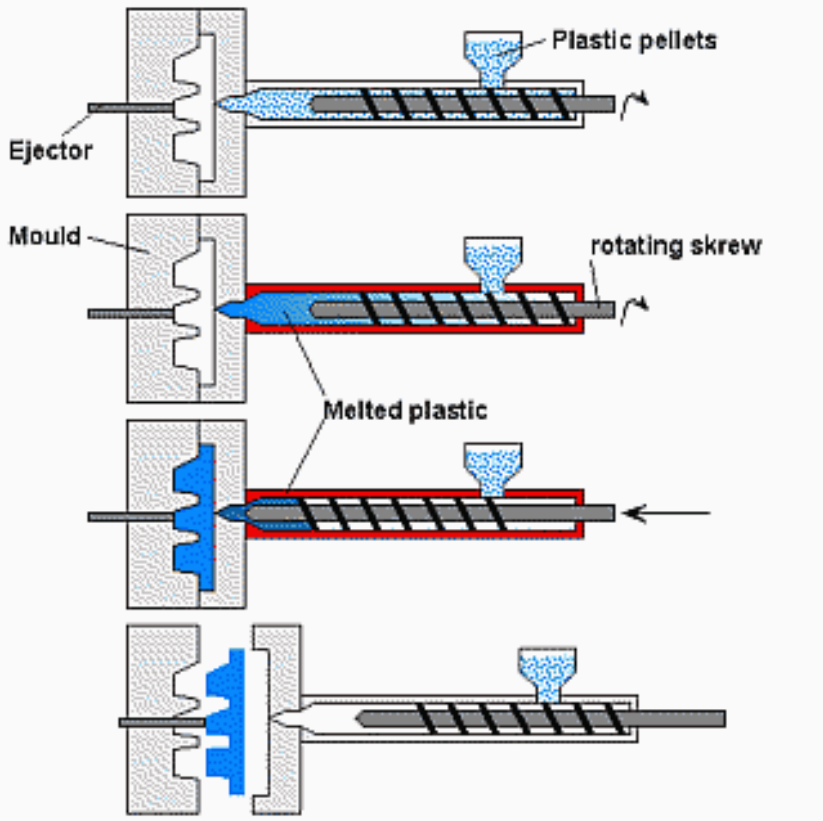


Illustration 1 – Working principle of a modern injection moulding machine, courtesy of www.design-insite.dk

Injection moulding of plastic parts is usable for all sizes which require accurate and complex geometry. Usually granular plastic or pellets are melted by friction with a rotating screw and actual heating, and then injected into the mould by a ram. Once cured the in the mould under pressure, the finished part is ejected, usually using ejector pins.

Injection moulding is usually reserved to thermoplastics, but it can be used for shaping thermosets and elastomers as well.

When shaping composites, parts with optimal mechanical properties cannot be produced as the content of added fibers must be limited due to restrictions in the flow properties. Production volumes are medium to large, and the cycle time per part is very short in the order 5sec-2min.

The mould is normally very expensive to fabricate, since it is often made from hardened steel in order to withstand high pressure and temperatures. The mould cavities in are commonly made with Electric Discharge Machining (EDM), which is a very costly was of producing due to high tool costs. Most moulds are equipped with heat or cooling circuits in order to control the mould temperature precisely during production.

8 Hypothesize

The aim of this study is to explore the behaviour of glass fibers in PS and PEI. Through several experiments the report will investigate;

Investigate the effects of the glass fibers on the replication of polymeric ribs.

Surface replication quality of injection moulded parts with and without glass fibers added to the moulding compound.

- Edge replication quality is expected to be purer in specimens with added fibers than counterparts without fibers. Furthermore it can be expected that more defects in the geometry will occur in specimens with glass fibers than counterparts due to poorer flow capability.

Effects of glass fibers on bonding between two injection moulded polymers.

- We expect a poor binding between the two polymers unless the last moulded part has the same ore higher melting temperature as the first one.

Investigate fibers orientations based on the injection parameters

Effects of the injection parameters on the surface roughness/quality.

- The injection pressure in the injection moulding machine will have an effect on the surface, greater injection pressure is expected to produce a finer surface structure, or a better replication of the mould surface.
- From theory studies we expect to see a higher roughness in the surface when glass fibers are added compared to samples without glass fiber. The fibers will create a more coarse grained structure, due to clothing.

Glass fiber distribution in different cross sections.

- It is expected that there will be a smaller amount of fibers in the far from the gate than close to.

Glass fiber orientation in different cross sections.

- We expect there will be a difference in the orientation of the fibers in a cross section close to the gate and far from the gate. We expect the fibers to be more unorganized far from the gate than close to the gate.

Geometrical size effect on the amount of glass fibers in the post moulded plastic parts.

Effect of glass fibers on the filling of the mould and effect of thin rib geometry on the distribution and amount of glass fibers in the ribs.

- We expect the thin ribbed geometry to have an effect on the distribution of the fibers. The fibers are about Ø 5-10 μm and 50-100 μm in length. The PS with fibers may have more difficulty filling the thinnest of the ribs than in the case

of PS without fiber, because of the lower flow capability caused by the fibers. We expect that PS with glass fiber will be evenly distributed through the part, but that distribution and orientation of fibers will vary according to injection parameters.

Extra studies

Effects of glass fibers on the tensile strength of PS.

- In a tensile testing machine we aim to test the tensile strength of both PS and PS with glass fibers. We except, that the glass will have an effect of the tensile strength, but also on the modulus of elasticity. The glass will hold the PS together, and will increase the tensile strength, but reduce the elasticity module.

Numerical studies of melt flow advancement in specific geometry, using MouldflowExpress.

- We expect the mould to be filled evenly from the gate and to the end of the part, maybe with a bit of turbulence in the end. Fibers are expected to give difficulties distributing the PS to the thin ribs

9 Test Methods

A number of different measurement approaches were combined to investigate effects specified in the hypotheses. Methods used for specific objectives are presented in Table 2 below:

Test objective	Method
Tensile strength	Tensile testing machine
Part quality from parameter change	Moulding machine
Distribution of fibers in the ribs	Chemical test and LOM C microscope
Distribution of fibers in the moulded part	Chemical test
Direction of fibers	LOM E microscope
Change of fibers after moulding	Chemical test and LOM C microscope
Sharpness of edges	LOM C, LOM E and SEM microscope
Surface roughness analyses	Laser scanning (UBM)
Surface of fracture	SEM microscope
Fiber size	Chemical test, LOM C and SEM microscope
Mould flow	Solid works mould flow
Mould Defects	LOM C, LOM E
Melt Flow Simulation	Solid Works MoldFlowExpress

Table 1 - Test methods

10 Sample production by injection moulding

The test specimens used for this study were produced on a machine placed at DTU´s Polymer Lab in building 427. The machine type: Engel ES 80/25 HL-Victory had a maximum tonnage of 25, and was numerically controlled.

Picture 2. Left: Injection moulding machine used at DTU Polymere Lab
Right: Close-up of mould.

10.1 Test specimen

The test specimen used for our experiments was originally designed for a study called "Investigation of polymeric microstructure replicated by 2k injection moulding", performed in cooperation with Danish company Sonion Roskilde A/S.

The specimen measures 12,54 x 12,54 mm and is designed to deliver a variety of different rib thicknesses and heights in order to perform investigations on the rib geometry's effect on the plastic injection flow. A complete description of the geometry is presented in appendix : 13.1: "Test Specimen geometry".
In our studies we focused our investigations on effects occurring around the so called "critical section" highlighted on Figure 4 below:

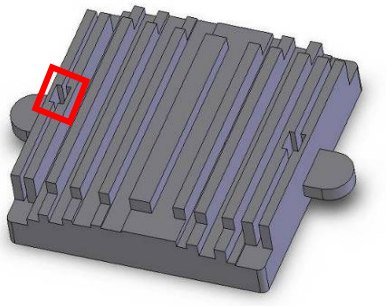


Figure 4. Critical section highlight

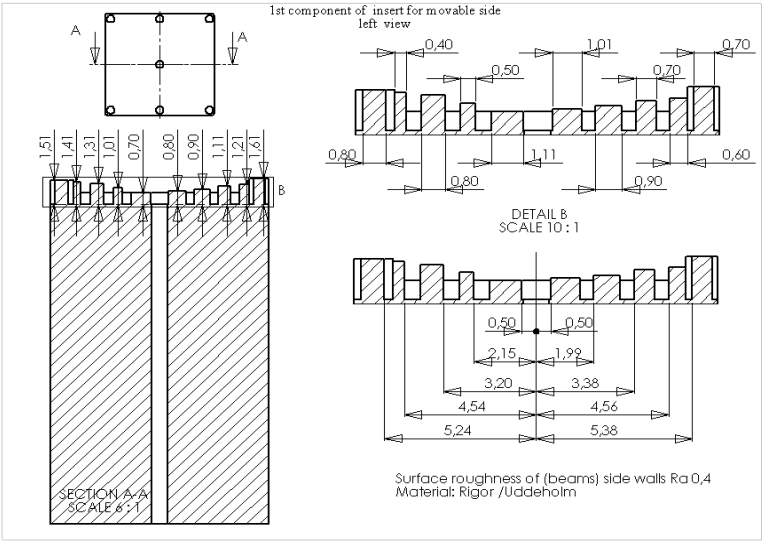


Figure 4. Drawing of insert used for injection moulding.

10.2 Mould defects

The specification of our specimens demanded that they were produced out of Polystyrene, however the mould delivered from Sonion had a serious defect which complicated the moulding process. Upon installation in the DTU machine we discovered that the heating circuit of the mould was broken, and neither we nor the workshop personnel were able to fix the broken circuit within the scope of the project period. The broken heating circuit meant we did not achieve constant mould temperatures higher than 29 °C during our production. The data sheet for PS 158 K recommended a mould temperature of 60 degrees C. Initial tests with PS were preformed, but gave poor and unacceptable results. Errors were that the injection mouldings did not fill entirely, and could not be removed from the mould without damage, due to the unheated mould.

The recommended melt temperature of PS 158 K is set at 235 degrees C according to Appendix no. 20.1.

Instead of using PS for all of our injection mouldings we opted to use PEI which can be moulded at much higher melt temperatures than PS. We hoped that the warmer melt flow would compensate for the low mould temperature, although the recommended mould temperature for our specific PEI polymer was 115 degrees C.

More info on the specific PEI used can be found in appendix no20.2 and 20.3. With PEI instead of PS we managed to get acceptable specimens with complete fillings and no damage when the piece was removed from the mould.

10.3 Production Setup

Our injection moulded samples were produced in series with characteristics as shown in Table 2. In total 7 different series were produced. From each series we produced between 6 and 15 pieces.

Series no.	Material	Glass fiber content [weight%]	Melt temp [C°]	Mould temp [C°]	Injection Pressure	Injection speed [mm/s]
1	PS	0%	235	29	2400	102
2	PS	30%	235	29	2400	102
3	PEI	0%	380	29	2400	95
4	PEI	30%	380	29	900	59
5	PEI	30%	380	29	1500	77
6	PEI	30%	380	29	2100	91
7	PEI	30%	380	29	2400	95

Table 3: Injection moulding characteristics.

Due to the poor replication surface quality of the PS samples we decided only to use these specimens for the chemical analysis to determine variation of fiber content in different rib thicknesses. Before moulding with PEI, granulates were dried at 150 °C for 2 hours to ensure that all moisture had vaporized from the plastic.

For our tensile tests on PS we were provided with samples that were already produced in advanced. Same parameters were used for both with and without glass filled PS during the injection moulding of these test specimens.

Finally a series of 2 component mouldings were made to investigate bonding between PS and PEI. The procedure was, that a piece of PEI at made at recommended setting were inserted into our empty mould, and then a shot of PS at recommended settings (except for the defect mould temperature) were injected to finish the two component mould. An overview of the 2component samples is presented below:

Series no.	Material	Glass fiber content [weight%]	Melt temp [C°]	Mould temp [C°]	Injection Pressure	Injection speed [mm/s]
8	1st PEI	0%	380	29	2400	95
	2nd PS	0%	235	29	2400	102
9	1st PEI	0%	380	29	2400	95
	2nd PS	30%	235	29	2400	102

Table 4: Production parameters for two component samples

11 Tensile strength experiment

11.1 Objectives of experiment

1. To observe the behavior, and measure the material properties of the polymers PS 158K, and PS 158K – 30% glass fiber under tensile load.

2. Compare the two materials mechanical properties.

The tensile strength test contains of the two samples of polymer:

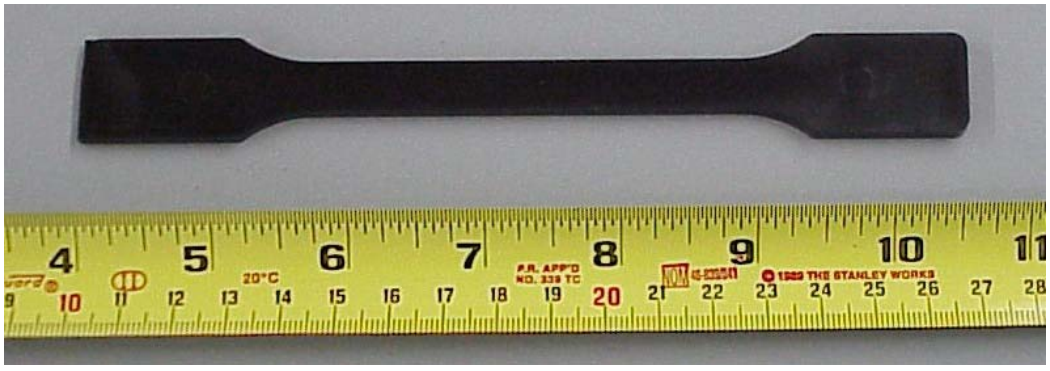
- PS 158K (transparent)
- PS 158 K with 30 % glass fiber.(non transparent)

When PS 158K is mixed with glass fiber the tensile strength increases. Therefore test for PS 158K with and without glass fiber are chosen so the samples and test results can be compared.

11.2 Test Methods

Tensile test

In the tensile test the samples of PS 158K and PS 158K 30% glass fiber are subjected to a tensile stress. The test specimen chosen for this experiment was an ISO 527 recommended tensile bar.

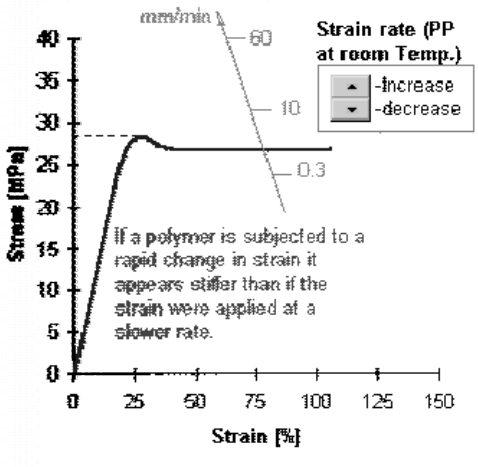


Picture 4: Test type specimen with geometry complying with ISO 3167

Cross section measurements[1]:

150 mm long
10 mm × 4 mm at center section

The sample length and cross sections are measured before the tensile test.
Tensile bars were stretched at a constant rate until they broke, by means of a tensile testing machine. The sample was secured in place between the grips of the machine, and the stress/strain curve was recorded on a PC connected to the test machine.



Picture 5: Example of typical stress strain graph

From the graphs the ultimate tensile strength can be observed and the extension, elastic modulus can then be calculated in order to compare the samples.

Picture 6: Extensometer and tensile strength sample made from BASF PS 158 K

[1] http://www.ptli.com/testlopedia/tests/ISO_test_specimen_3167.asp

Scanning electron microscope (SEM)

Picture 7. SEM located at DTU building 204.

We chose perform a closer inspection of the tested samples by means of a SEM analysis. SEM provides excellent quality pictures of what is going on at the micro level of the material, observation of this can help to give a precise analyse of why fibers give the materials the larger strength, and give an idea of how the fibers act in the moulded material.

Polarized microscope

The way that a polarizing microscope can see is called anisotropic, because the split light rays into two secondary rays. These rays travel with different speed and in different direction, and are recombined outside the crystal, where they are out of phase. This causes interference. The material, (if transparent) is seen as having different colours. The colour spectrum can be used to interpret stress levels within the polymer[2].

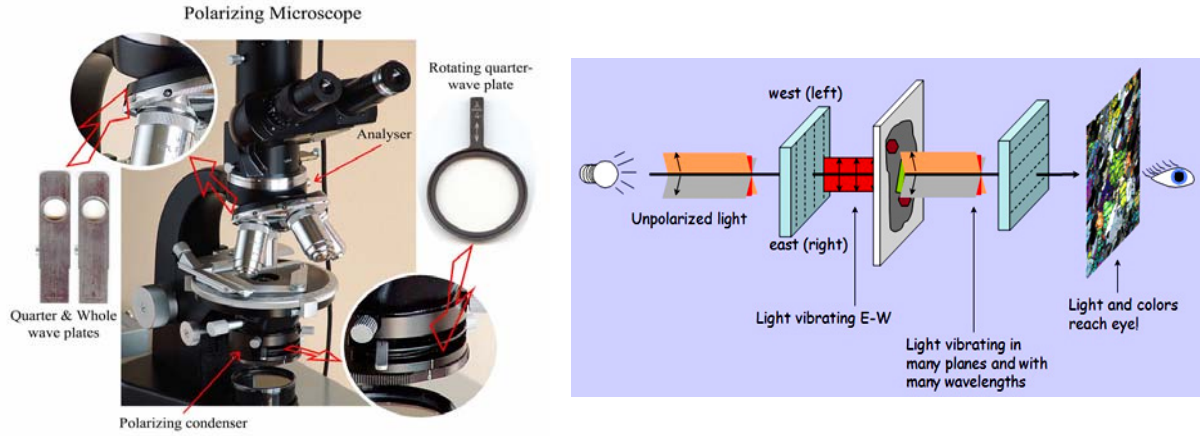


Illustration 2: Working principle of a polarised microscope.

The polarized microscope can then reveal the stress difference in the material before and after the tensile test, this give an idea of how the stress is distributed in the moulded samples.

[2] http://www.microscopy-uk.org.uk/mag/artjan05/bjcomp.html

11.3 Results

Tensile strength test:

The figure below shows examples of applied force plotted against extension for the two types of samples that underwent a tensile test until failure.

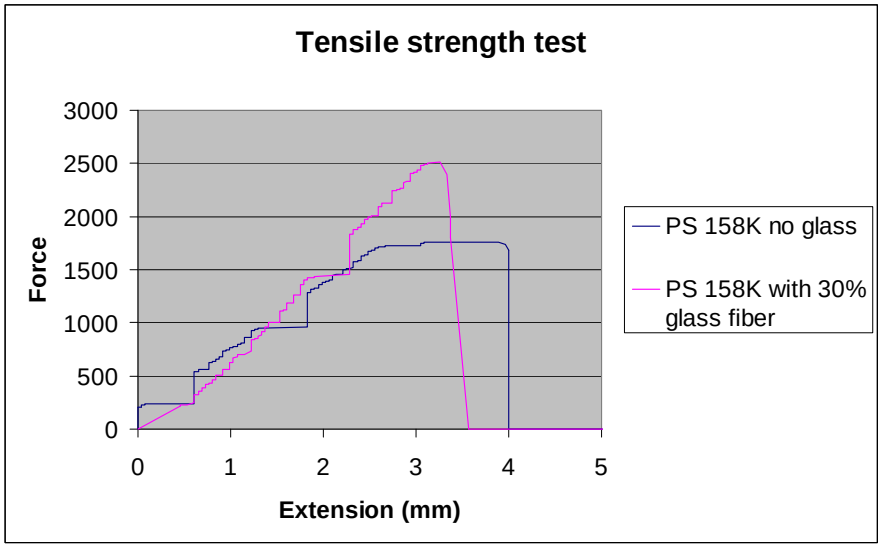


Table 5 Example of tensile test graph

When the two lines in the graph are compared, it is clear that the blue line fails around 1700 Newton where the reinforced glass fiber sample fails at around 2500 Newton. It's also noticeable that the blue line has a longer period plasticity than the glass fiber reinforced sample.

Test scheme:

Material	Ultimate tensile strength [N]	Rupture strength [N]	Extension at failure [mm]	Young's modulus[GPa]
PS1 no glass	1761	1682	4.005	1.63
PS2 no glass	1776	1760	5.007	1.37
PS3 no glass	1810	1761	4.920	1.3
PS4 no glass	1807	1797	4.539	1.3
PS1 with glass	2447	2335.5	3.089	2.23
PS3 with glass	2509.9	1799.9	3.373	2.06
PS4 with glass	2314.9	2186.7	3.39	1.93
PS5 with glass	2131.6	2979.7	2.86	1.94

Table 6 – Results of tensile tests.

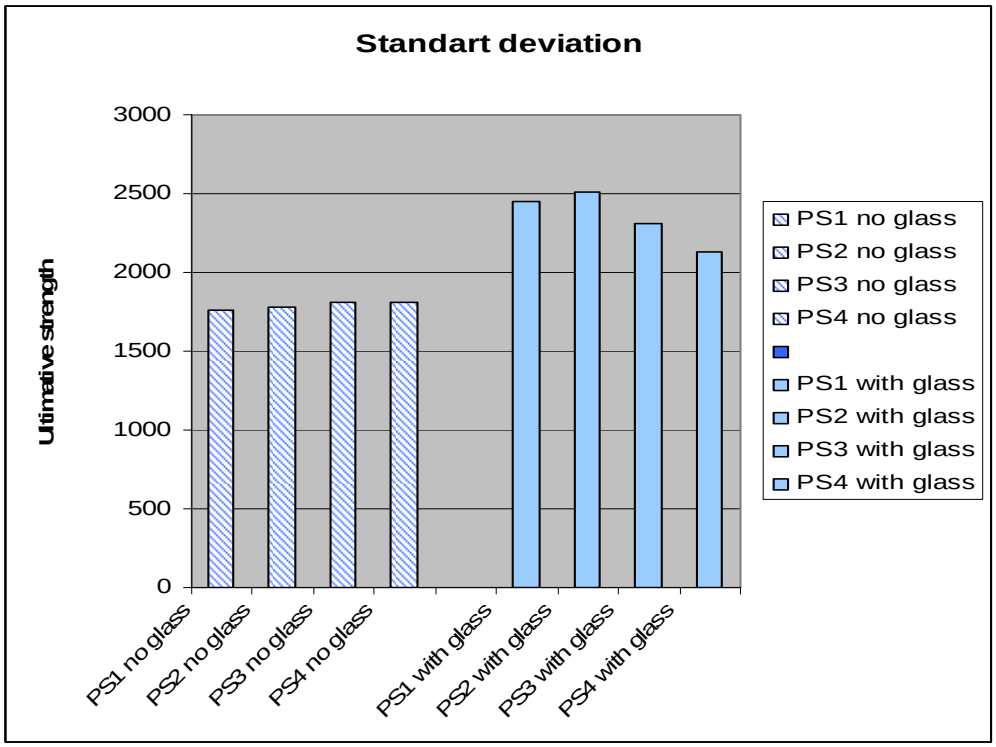


Table 7

The graph shows how the samples deviate and the average for the test with and without glass fibers are:

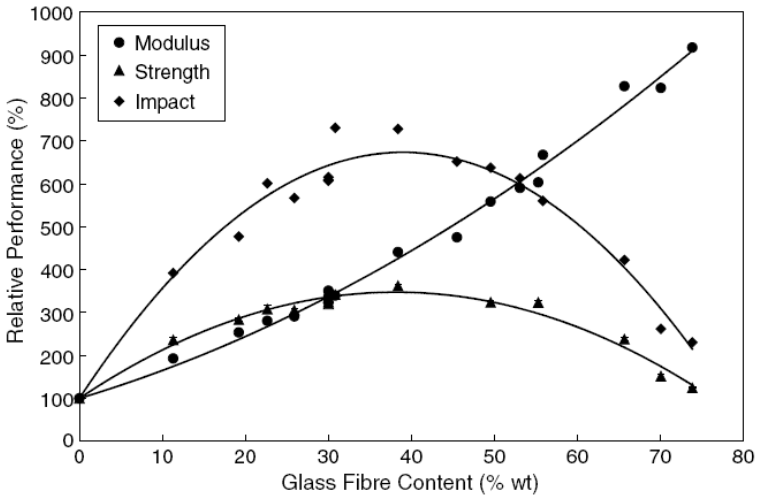
No glass: 1788.5 N
With glass: 2350.8 N

The approximated strength incensement for PS 158K with 30 % fibers is:

$$Strength\ increase = \frac{1788.5 \cdot 100}{2350.8} = 76.08 \approx \underline{24\%}$$

Conclusion on the tensile test graph

The scheme shows the values for the samples preformed in the tensile test machine. The UTS (ultimate tensile strength) shows that the glass fiber enhanced materials have much higher UTS and rupture strength than the samples without glass fiber. The EAT (extension at failure) shows that the polymer without glass fiber is more elastic than the glass fiber enhanced ones. Young's modulus is also much higher for the glass fiber enhanced polymer.
This means that the glass fiber enhanced polymer can stand up to higher impact of force without loosing its shape, compared to the polymer without glass fiber. But it also means that the material will get stiffer and more brittle, and this can cause difficulty when moulding
For more details on the data for the test samples and calculations, see appendix 21.



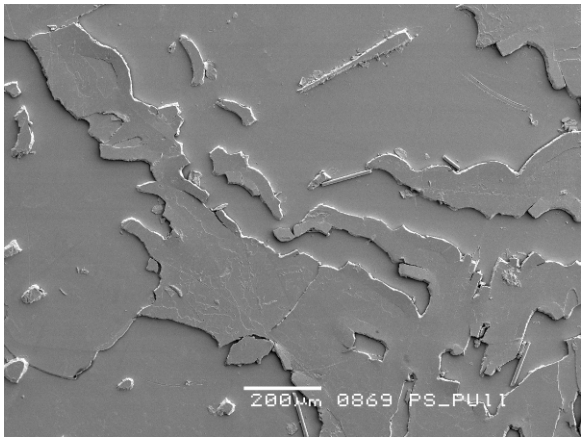
Graph 1: Influence of % fibers on material performance

The graph shows the reaction on the material from the amount of glass fiber in the material, and it actually shows that if the glass fiber excites 40% in the material, it will begin to decrease in strength, and get weaker[3].

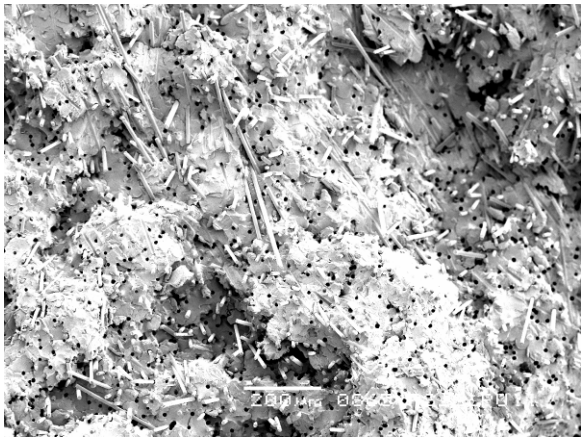
[3] The influence on fiber length and concentration on the properties of glass fiber reinforced polymer: by J.L. Thomason

Scanning electron microscope analysis

When put into SEM (scanning electron microscope) the fracture surfaces of the tensile samples can be investigated.



Picture 8: PS 158K at fracture surface of tensile bar.



Picture 9: PS 158K +glass at fracture surface of tensile bar.

Conclusion on SEM for tensile test

In Picture 9 the surface of the fracture is smooth and clean.
This is because that the fracture follows the slip planes of the polymer.

In Picture 10 the surface of the fracture is very chaotic. This shows that the glass fiber changes the dislocation glide plane by interrupt the slip plane, in a way so the fracture has to change to new planes when glass fiber blocs the way of the slip plane in the polymer, and thereby creating a stronger material.

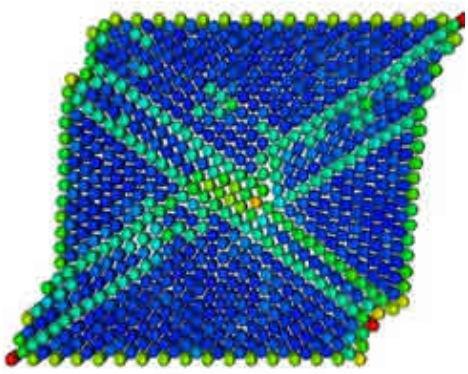


Illustration 3: Example of dislocation on the slip planes of material

Polarized microscope

When put into the polarized microscope the stress level at different places can be seen form the coloured light. Our tensile test bars are shown below:

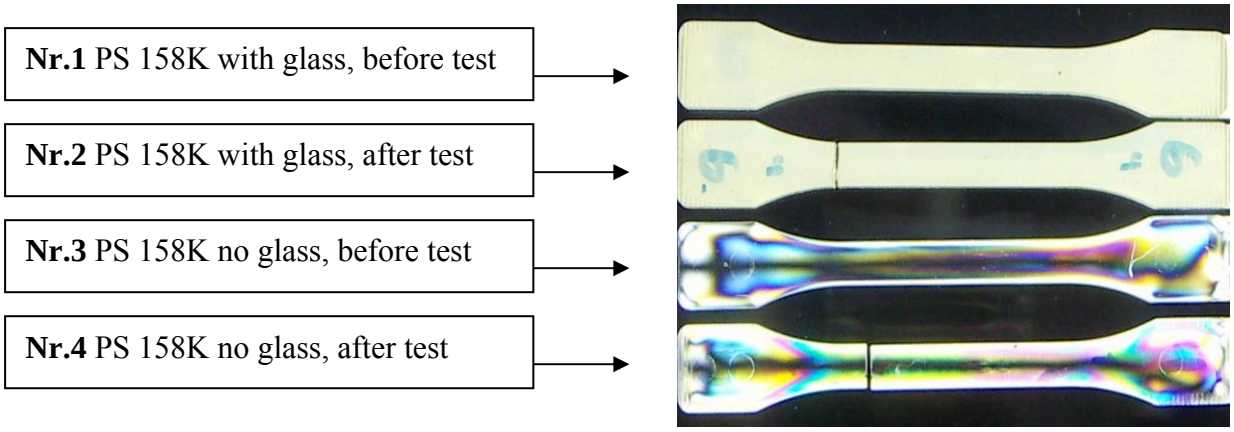


Illustration 4: Tensile test bars examined under polarized light

As seen on Illustration 4, sample nr.1 and nr.2 with glass fibers doesn't allow the light to pass through it, making it impossible to get a result from it.

But samples nr.3 and nr.4 without glass fibers shows a nice color spectrum, if seen closely sample nr.3 which is the sample before the tensile test, has a broader light spectrum that covers the entire width of the sample in the thin part.
Sample nr.4 which is the sample after the tensile test shows a much thinner light spectrum in the thin part of the sample.

The reason that the light spectrum is thinner on sample nr.4 is because that, when the samples are moulded, the polymer that hits the wall of the mould fist will solidify quickly and thereby create a lot of internal stress in the material, but the tensile tests force makes a lot of this build up stress disappear, leaving only the center of the sample with internal stress.

Conclusion on polarization microscope analysis

Even though the result from the glass fiber samples cannot be used, the same thing happens in the mould for both samples: they get internal stress from the rapid cooling of the mould. To eliminate this phenomenon, one way could be to heat the mould so the melt didn't cool of so quickly, but this would of course result in longer cycle's time for the parts.

11.4 Discussion

The results presented show the difference in behaviour between polystyrene and polystyrene when it has been reinforced with glass fiber.

Sources of error

The amount of fibers can vary from sample to sample, which makes every sample unique with its own variation of strength.
If young's modulus for PS 158K is looked up in the data sheets its value should be App. 3-3.4 GPa. [See appendix no. 21]
The results for young's modulus in this experiment has been calculated to App.1.6 Gpa.
The error can be because of the measured length of the tensile bar used to calculate young's modulus. The length is too long (107 mm.) where it should have been around 10 mm, often when the same types of material are tried in two different extensometers they will give different values. The error can also lie in the moulding of the samples, the average cross section on the sample bar has shown to vary, which can cause the result to deviate.

Difference in behaviour between the samples

The preformed tensile strength tests show that, the strength of the glass fiber enforced polymer is stronger than without glass fibers. As expected we found a decrease in the elasticity module of the material when adding glass fibers.

This could be a disadvantage because the glass fiber makes the polymer more brittle. One of polymers big advantages is, their ability flex under load.
The difference between the brittleness of the two test samples it not a big difference, but still noticeable, and should be considered when deciding whether to use fibers reinforced plastic or not.

12 Sharpness and surface quality

12.1 Objectives of the experiment

1. To observe how the surface quality and edge sharpness in injection moulded ribs are affected for PEI alone and PEI with 30% glass added.

2. To observe if two component moulding between PEI and PS 158K is affected by adding glass fibers to one component (PS).

The investigation will be performed on four types of samples:

1. PEI
2. PEI 30% glass fiber
3. PEI and PS 158K (two component injection moulding)
4. PEI and PS 158K 30% glass fiber (two component injection moulding)

Preparation of samples

Moulding:
In the experiment samples have been moulded related to the four types of samples to be investigated. The samples have all been made with the same injection parameters (see table 1) for comparative reasons.

Grinding and polishing:
The samples that contained two component materials (see pictures below) were grinded down to the critical section (see pictures below) and then water polished to make sure the surface is clear for grinding track.

Scanning electron microscope (SEM):
Samples were placed in a scanning electron microscope, (see pictures below) after being coated with a 10 Nano meter thick layer of gold, in order to provide a reflective surface for the electrons to bounce off.

Pictures from the SEM microscope were well suited for visual inspection of edge sharpness due to the great depth sharpness than can be achieved using this method in comparison to a traditional LOM microscope. SEM further provides the ability to view and rotate samples in 3D thereby easing inspection.

The moulded parts:

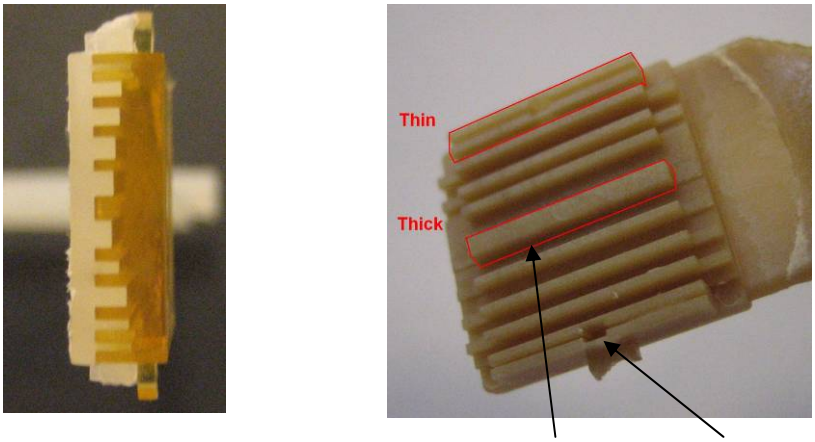
Nr.1 Two component material
PEI and PS 158K no glass fiber

Nr.2 Two component material
PEI and PS 158K 30% glass fiber

Nr.3 PEI no glass fiber

Nr.4 PEI 30% glass fiber

Picture 11 – Samples used for SEM inspection



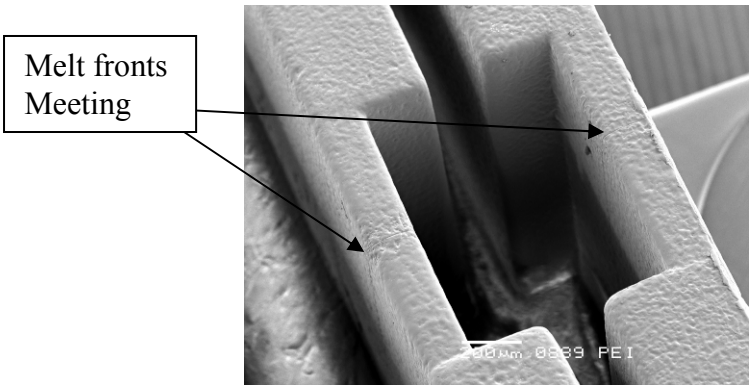
Picture 12 – Left: 2 component sample after grinding and polishing.

Right: Close up of sample with ribs and critical section highlighted.

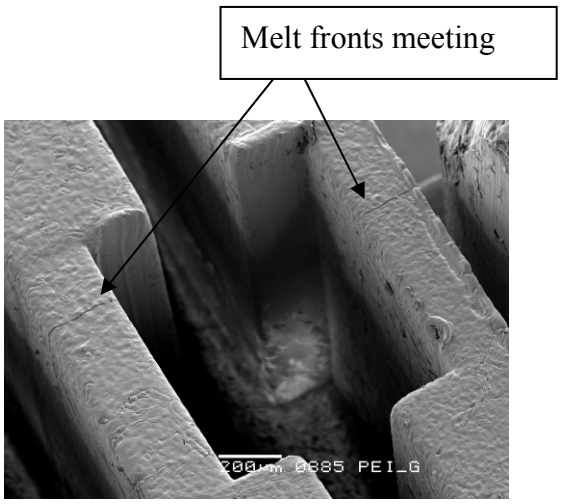
12.2 Results of SEM analysis

Pictures from SEM analysis are presented and compared below. After looking in the SEM, the pictures of the different samples containing of different materials, can be looked upon and compared, due to quality and sharpness of the ribs. The important issue in micro moulding is to get the material to fill the ribs as much as possible and get a part that has a good surface quality.

Magnification set to 200 microns:



SEM picture 1.1 PEI,
Critical section at 200 microns

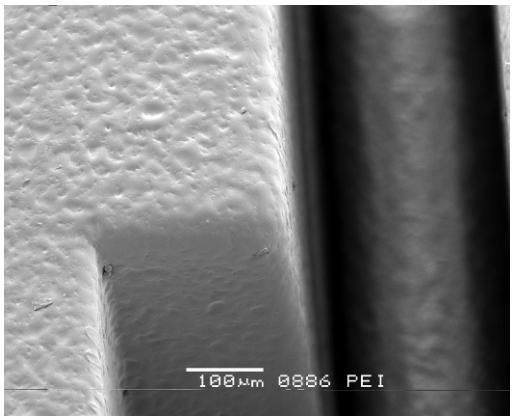


SEM picture 2.1 PEI 30% glass
Critical section at 200 microns

At SEM picture 1.1, the surface is not entirely smooth, there are small waves like dislocation but not something to worry about and the edges has a small roundness. Its looks like PEI have filled the ribs in the mould quite nicely.

At SEM picture 2.1, the surface resembles those of section 1.1, but more visible melt errors are visible around the edges. However the filling of the critical section is still acceptable.

SEM is zoomed in to resolution of 100 microns:



SEM picture 1.2 PEI
Edge of critical section at 100 microns

SEM picture 2.2 PEI 30% glass
Edge of critical section at 100 microns

Examination of picture 1.2 and 2.2 reveals obvious differences in the sharpness of the corner edge. The sample on picture 1.2 with no glass fibers achieves very nice edge that has a little roundness but is smooth and constant. At picture 2.2 the top surface of the sample resembles that without fibers, but the vertical edge surface has cracks and there are places of outflow, and the replication quality is significantly worse than on picture 1.2.

To check if the PEI 30% glass fiber surface roughness if consistence for the entire part, the SEM was guided to the middle rib, this is the thickest rib on the specimen.

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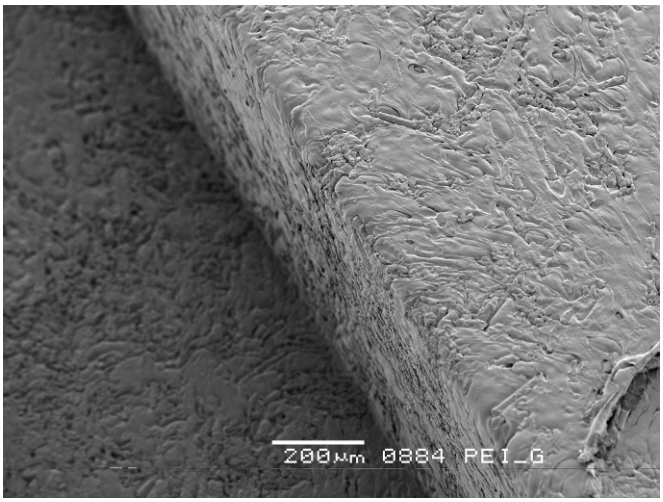


SEM picture 2.3. Of PEI 30% glass fiber Middle rib at 200 microns

At the middle rib it can be seen that the surface has a lot of fibers layered in the surface. This affects the smoothness of the surface. There are still flaws in the part.

12.3 Mould flow analysis using MoldFlowExpress

In pictures SEM picture 1.1 and SEM picture 2.1 it was observed that two melt fronts meet in ribs of the critical section. In order to understand this effect, a numerical simulation of melt front advancements was constructed using the MouldflowExpress application found in the Solid Works software package. The simulation is presented on screenshots below.

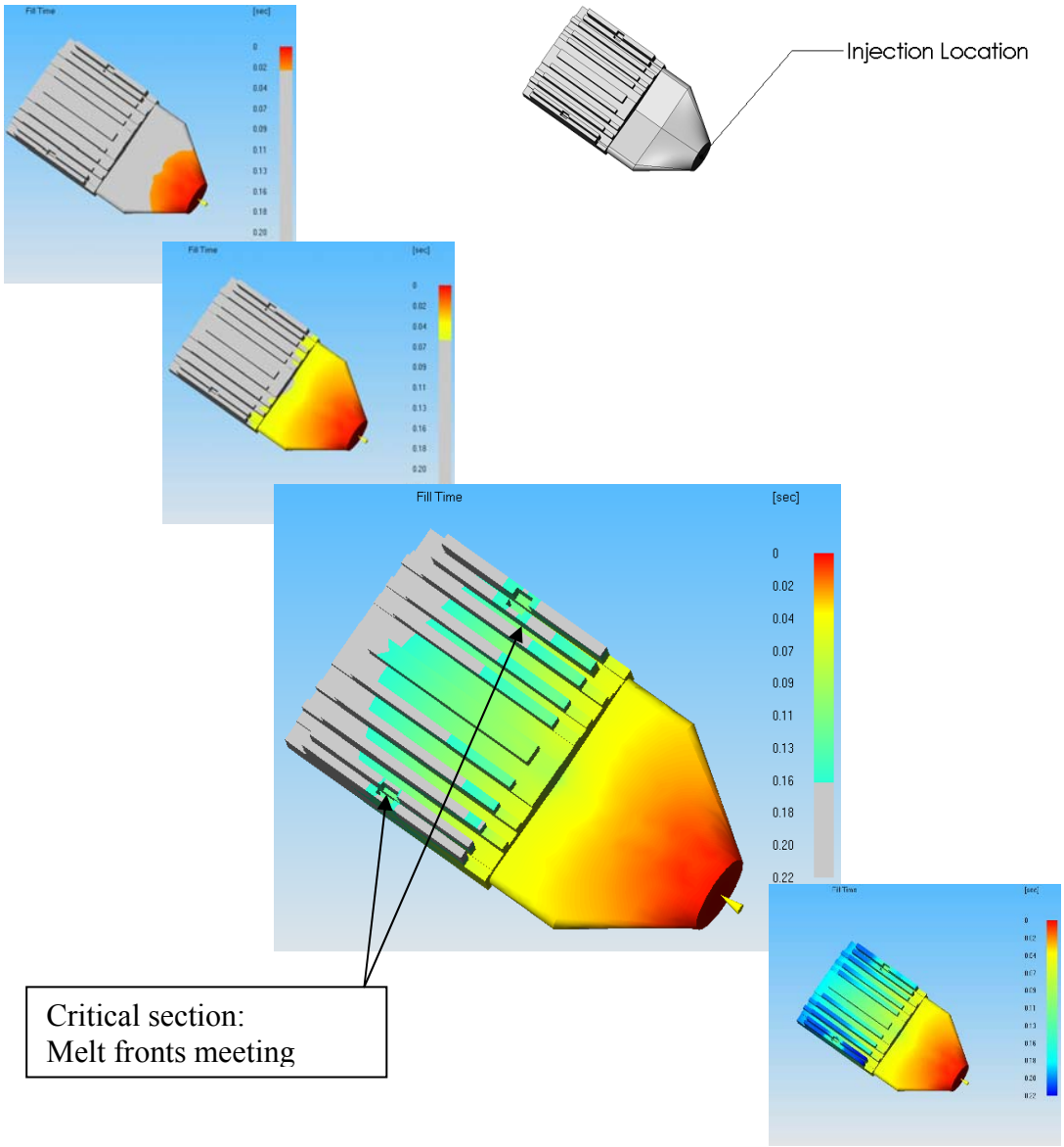
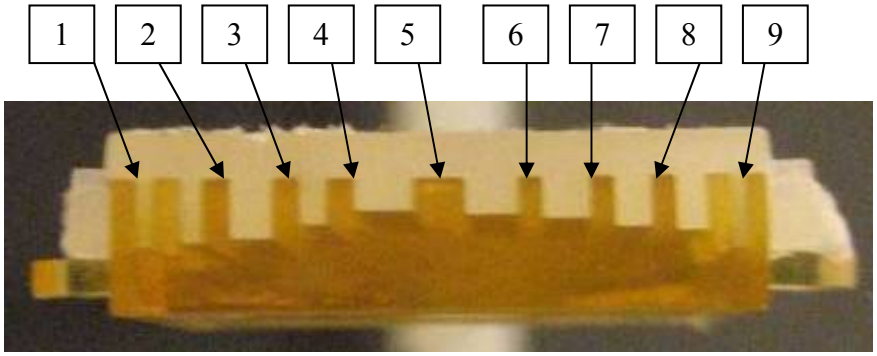


Illustration 5. MoldFlow analysis sequence.

In the flow sequence it can be seen that the narrow rips actually creates resistance, so the melt advances through the thickest part of the ribs firstly, and then after completely filling this, begins to fill the thin rips. This effect creates two melt fronts in the longitudinal direction of the thin rib. As seen on the SEM pictures our numerical simulation shows that the progressing melt fronts will actually meet in the middle of the critical section.

13 Two component injection mouldings

For the two components moulding the objective was to look at how the two materials have bonded with each other. When the two fronts of the materials meet they will become one. It is important that the two materials achieve a good welding, in order to make micro parts of more than one material.



Picture 13: Cross section of two component sample

To get a better overview of the sample, each rib was numbered in order to avoid comparative mistakes.

13.1 Samples

PEI moulded with PS, both without glass

Fig. 3.1 SEM picture of rib nr.1
PEI and PS 158K no glass

Fig. 3.2 SEM picture of rib nr.3 and 4
PEI and PS 158K no glass

In fig. 3.1 It's clear that at the edges of the sample, have not bonded correctly. Separation is clearly visible.

In fig. 3.2 The fusion of the materials is now much better. There are no obvious cracks. However there seems to be a ledge or difference in elevation between the two different materials. This is caused by the grinding process that wears of the softer material (PS) more rapid that the hard one (PEI).

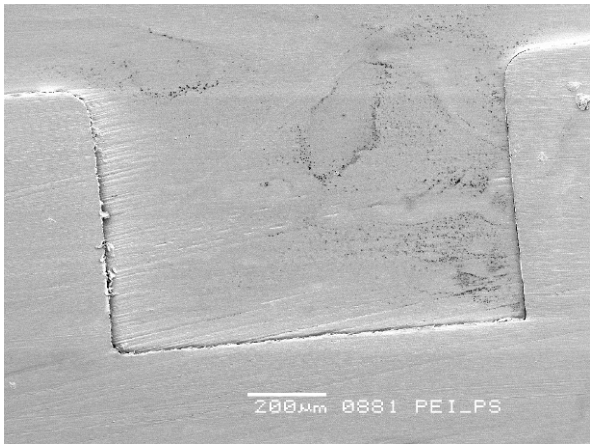


Fig. 3.3 SEM picture of rib nr.5 and 6
PEI and PS 158K no glass

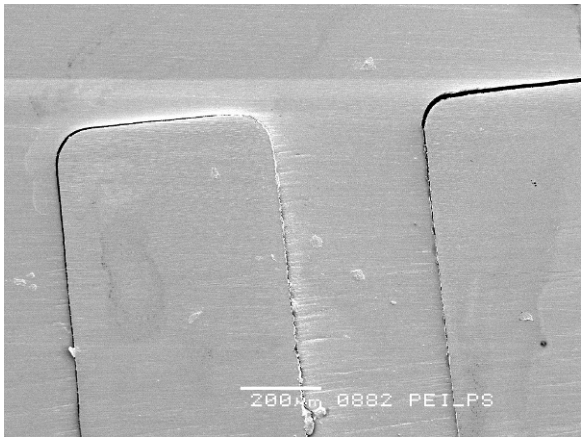


Fig. 3.4 SEM picture of rib nr.9
PEI and PS 158K no glass

In fig.3.3 The ribs are a bit wider, making it easier for the melt to flow and the result look nice. There are good fusion between the two materials and no cracks.

In fig.3.4 The edge ribs also shows that the material has cracks in the fusion area.

PEI and PS with 30% glass fiber

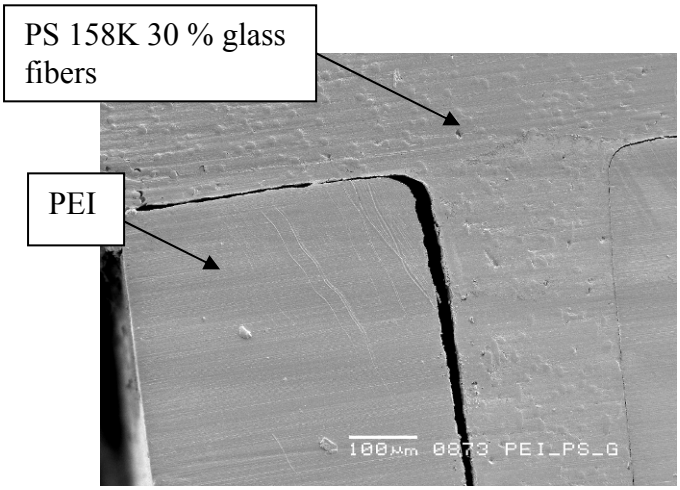


Fig. 4.1 SEM picture of rib nr.1
PEI and PS 158K 30% glass

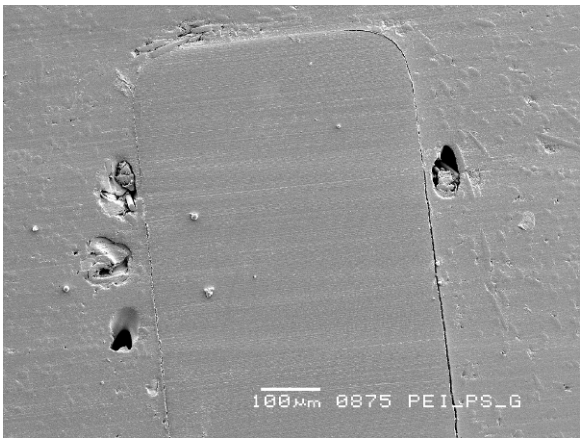


Fig. 4.2 SEM picture of rib nr.2
PEI and PS 158K 30% glass

In fig.4.1 The phenomena with separation along common edges occurs again.

In fig.4.2 The materials are connected better than on picture 4.2, however a small separation is still visible along the right side of the edge. Gas pockets are also visible close to the edges.

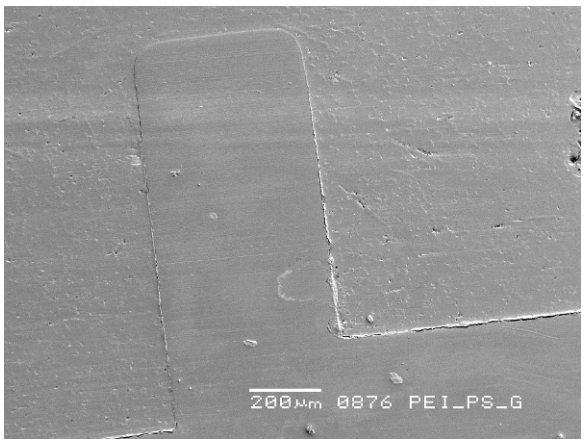


Fig. 4.3 SEM picture of rib nr.3
PEI and PS 158K 30% glass

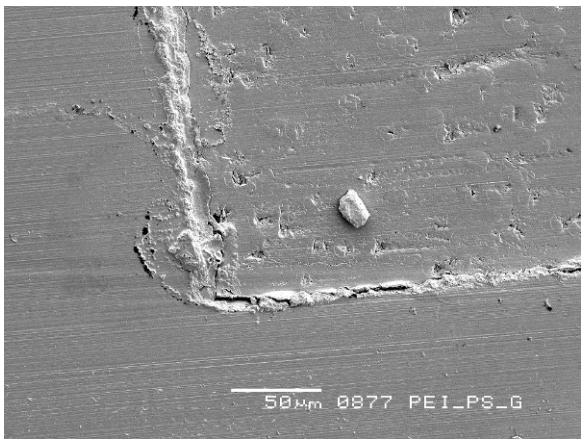


Fig. 4.4 SEM picture of rib nr.3 zoom
PEI and PS 158K 30% glass

In fig.4.3 The welding of the two materials looks much better than the outer ribs, in fig. 4.4 the SEM zoomed in at the welding area which shows that there are no tendency for gabs.

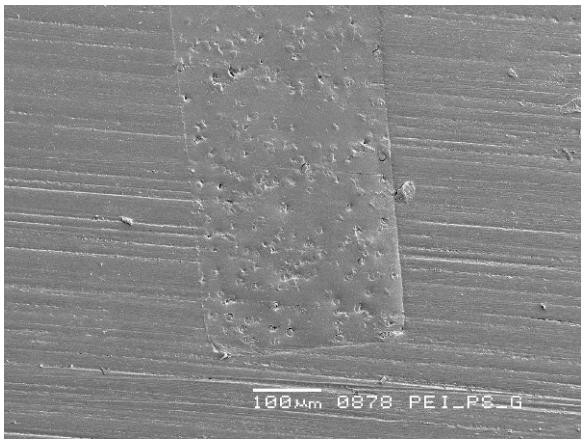


Fig. 4.5 SEM picture of rib nr.9 (at bottom)
PEI and PS 158K 30% glass

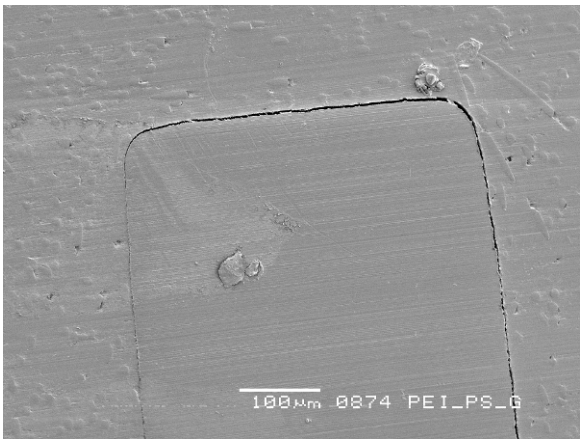


Fig. 4.6 SEM picture of rib nr.9 (Top)
PEI and PS 158K 30% glass

In fig.4.5 Shows a satisfactory weld between the two materials.

In fig. 4.6 At the other edge there is also gap between the two materials. One reason for the gap between the materials could be because, that the grinding and polishing has shaken the materials so that the melt fronts welding have been broken. In any case the weld between the two materials in this case is not satisfactory if used for high stress applications.

13.2 Discussion

The results clearly show that if the same parameters are used to mould polymer with and without glass fibers, the results will be different. The polymer without fiber achieves a better surface quality, and no flaws regarding complete filling of the critical section. Especially the vertical edge in PEI with glass has a reduced surface quality. The explanation is in the melt flow characteristics of fill and unfilled material. Unfilled material has a more homogeneous flow characteristics and better replication ability than the filled material. Glass filled materials are also more sensitive to part geometry, gate location and process conditions.
The fact that the fiber material is stiffer can explain why the edges are filled with cracks and flaws compared to the material without fibers.

When comparing 2-component moulding we did not discover significant differences between welding of materials with fibers and without. Both types of samples showed visible cracks especially along the outer rib edges. These cracks might have been introduced during grinding and polishing of the samples, but highlights the difficulty in bonding different polymers during injection moulding.

PS and PEI has different melting points, and when the insert is made of PEI which have a melting point at app.280 degree and the PS that has a melting point at 250 degree, is injected into the insert it won't melt the PEI very well making the fusion of the two materials more difficult. Also the two materials has different retractions reaction when cooled, this is something that could cause the cracks on the edges like in the pictures.

13.3 Conclusion on sharpness and surface quality:

As mentioned earlier the stiffness of the materials when added fibers goes up, making it more difficult to create sharp edges without getting crack both when cooling and when ejected from the mould.
The two materials do not have a very good ability to bond together because of the different melting temperatures and there retractions when cooling are different.
If the two material where switched, so the PS where the insert and the PEI where injected in, the result would probably look different because the melted PEI would melt the PS material and the fusion would be better, if the cracks would disappear is hard to say because of the different retraction.

14 Influence of parameters on moulding defects

14.1 The objective of the experiment

- Analyzes of the change in the samples caused by different injection moulding parameters. Samples are checked for errors in the filling of the critical section.

The changed parameters experiment, uses two types of polymers: PEI and PS 158K. Injection parameters are presented in the tables below.

Series no.	Material	Glass fiber content [weight%]	Melt temp [C°]	Mould temp [C°]	Injection Pressure	Injection speed [mm/s]
1	PS	0%	235	29	2400	102
2	**PS**	**30%**	**235**	**29**	**2400**	**102**
3	PEI	0%	380	29	2400	95
4	PEI	30%	380	29	900	59
5	PEI	30%	380	29	1500	77
6	**PEI**	**30%**	**380**	**29**	**2100**	**91**
7	PEI	30%	380	29	2400	95

Table 8

Series no.	Material	Glass fiber content [weight%]	Melt temp [C°]	Mould temp [C°]	Injection Pressure	Injection speed [mm/s]
8	1st PEI	0%	380	29	2400	95
	2nd PS	0%	235	29	2400	102
9	1st PEI	0%	380	29	2400	95
	2nd PS	30%	235	29	2400	102

Table 9

Note:
Series no. 2 and 6 were not included in this analyse

14.2 Method

Moulding
The moulding machine makes the samples, and the parameters for the different samples are changed on the machine

Microscope
When the samples are complete they are put under a microscope with resolution from 200 micron to 50 micron. Samples are then analysed to check for quality and defects at different parameter settings.

14.3 Results

Results are presented in the form of pictures from the LOM C and LOM E microscopes. The front figure numbers match the series number the material has in the table listing. After each series comments are made on the pictures.

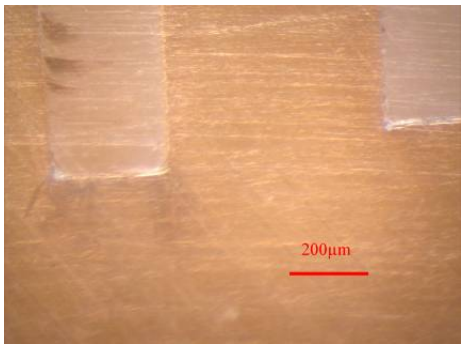


Fig.8.1 two component material PS and PEI no glass thick rib right

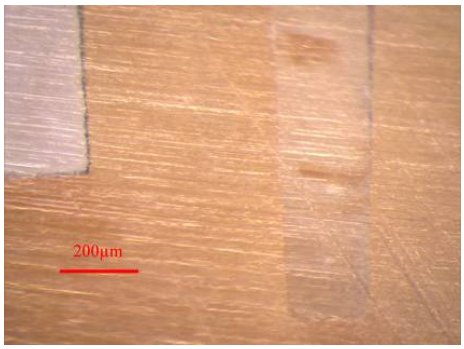


Fig.8.2 two component material PS and PEI no glass thin rib left

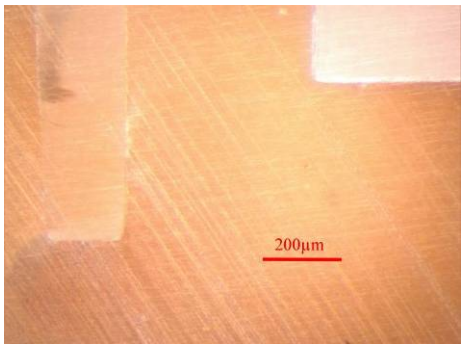


Fig.8.3 two component material PS and PEI no glass middle rib left

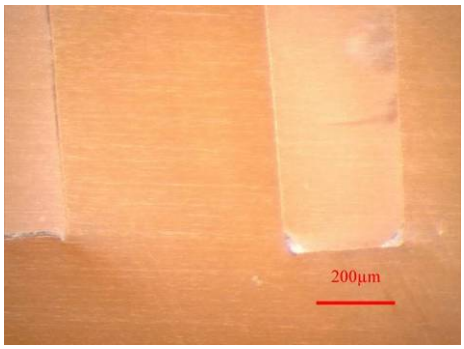


Fig.8.4 two component material PS and PEI no glass middle rib right

Figures 8.1-8.4 is PS combined with PEI
In Fig.8.1 if looked closely it can be seen that the transparent material (PS) hasn't filled the entire rib in the bottom.

In Fig.8.2 and 8.3 the PS seem to have filled the mould completely.

In Fig.1.4 it's very clear that there are problems filling the mould along the edges of the rib.

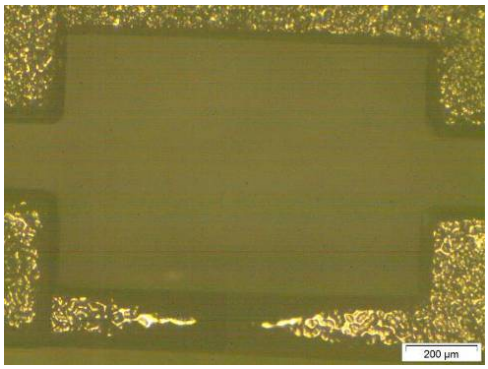


Fig.3.1 PEI 2400 bar
without glass

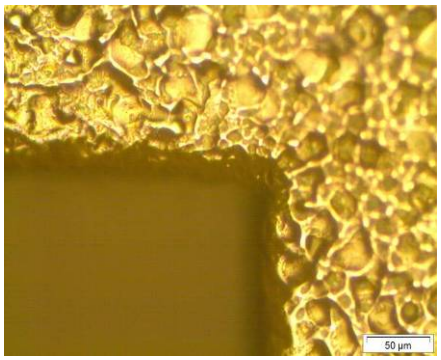


Fig. 3.2 PEI 2400 bar
Without glass

In Fig. 3.1 the critical section for PEI with no glass is pictured. There are some problems filling the mould in the lower edge, but the rest of the mould flow looks fine and there are no outflows or flaws.

In fig. 3.2 the same critical section now in the corner are shown for PEI with glass, and there are no flaws at the edge in the corner, which ensure a smooth surface and edge.

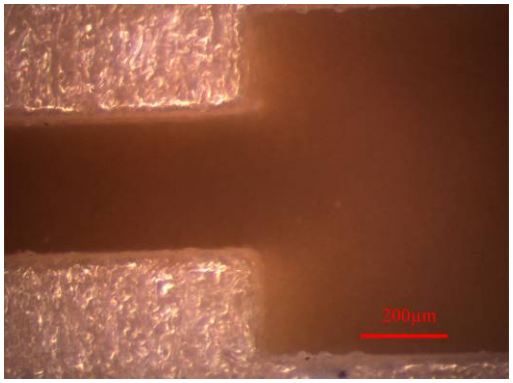


Fig. 4.1 PEI 900 bar
Critical section left

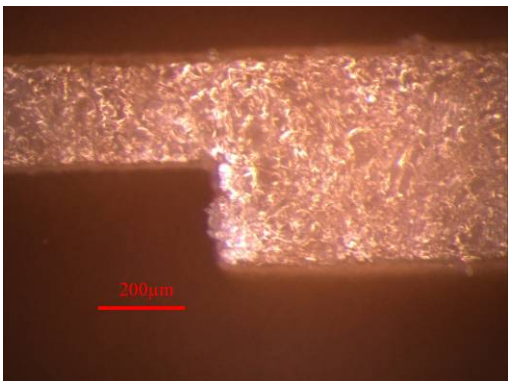


Fig. 4.2 PEI 900 bar
Critical section right

In Fig. 4.1 the critical section on the left side, it can be seen that the melt has filled the mould nicely and there doesn't seems to be any mould flaws.

In fig. 4.2 the right side of the critical section can be seen, and there seem to be a little outflow at the edge, not much but enough to destroy the smoothness of the edge.

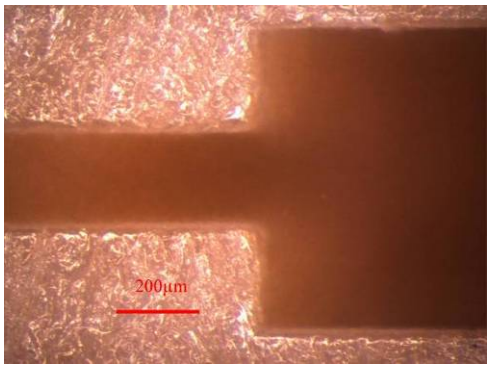


Fig.5.1 PEI 1500 bar
Critical section left

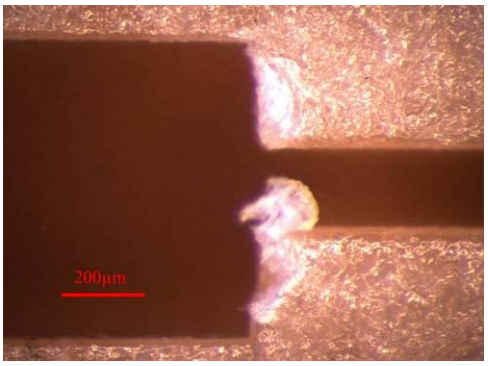


Fig.5.2 PEI 1500 bar
Critical section right

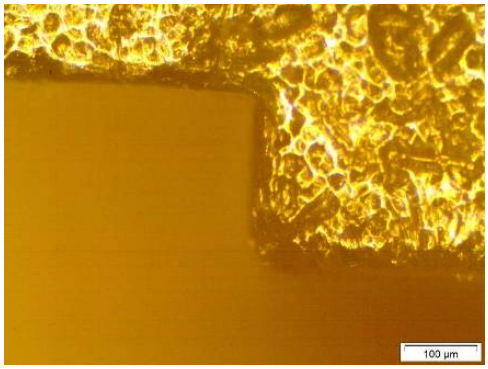


Fig. 5.3 PEI with glass
1500 bar

In Fig.5.1 and 5.2 the pressure has been increased from 900 to 1500 bars.

In Fig.5.1 the left side looks good with no outflow or defect.

On Fig.5.2 there is a huge outflow on the lower right side, this looks like if the melt on the edge haven't solidified properly and been hit.

On Fig. 5.3 the upper side of the sample right above the flaw have been analyses to check how the melt looks closer right beside of the flaw. The image shows that there's nothing wrong with the other side.

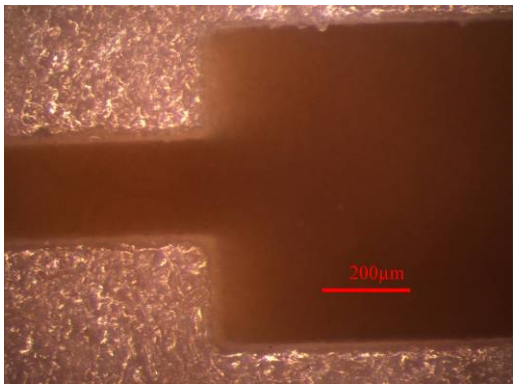


Fig.7.1 PEI 2400 bar
Critical section left side

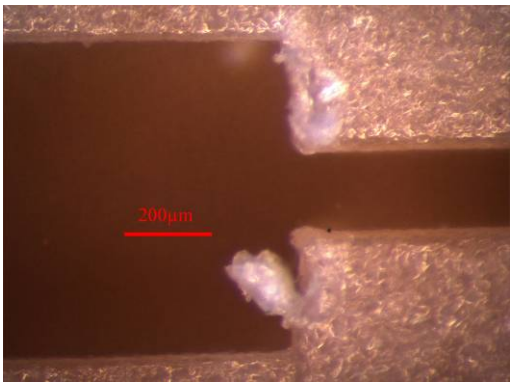


Fig.7.2 PEI 2400 bar
Critical section left side

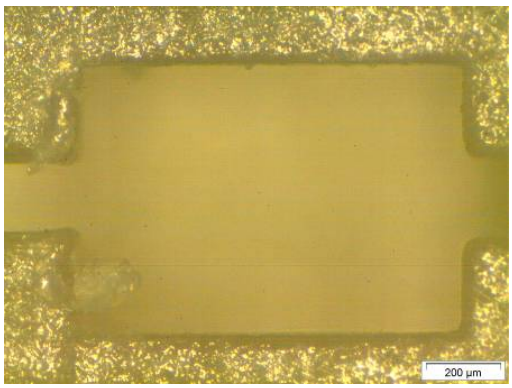


Fig. 7.3 PEI with glass
2400 bar

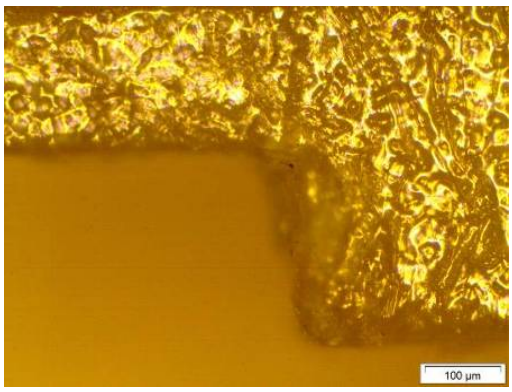


Fig. 7.4 PEI with glass
2400 bar

In Fig. 7.1- 7.4 the pressure is now increased to 2400 bars with temperatures injection speed at 95 mm/s.

In Fig.7.1 the critical section on the left side is seen, and the part looks fine, there are no obvious moulding defects.

In fig.7.2 on the critical sections right side, there are outflow and bad moulding on both the lower and upper part of the critical section.

In fig.7.3 the microscope are zoomed out to get an image of the entire critical section, to get an idea of how critical the outflows are.

If looked closely in the left lower corner there is a strange lever, like if the material takes at little step up.

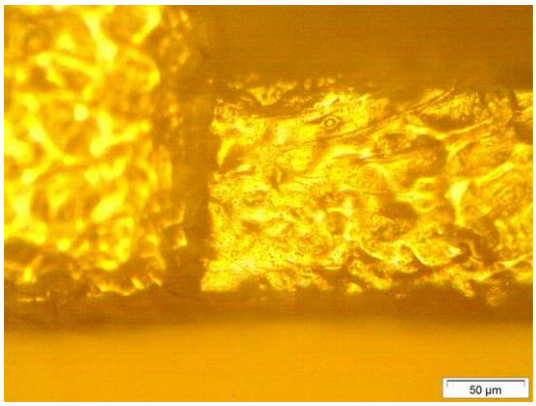


Fig. 7.5 Nr.6 PEI 2400 bar with glass

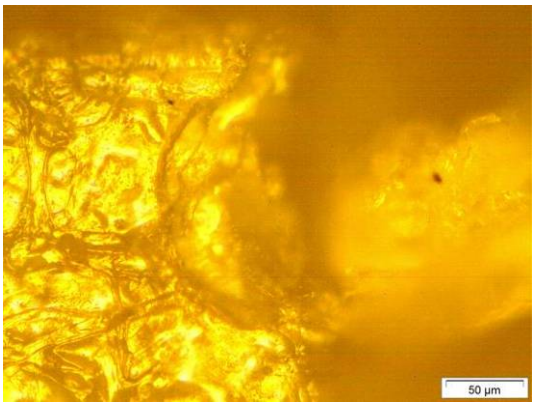


Fig. Nr.6 PEI 2400 bar with glass

In Fig. 7.5 and 7.6 the microscope zooms in at the strange behaviour of the materials in the lower left corner.

In Fig.7.5 it can be seen that there is some kind of problem when the two melt fronts meet, which creates an edge bubble that is not good for the quality for the part.

14.4 Discussion on moulding defects

The study revealed that in general, increasing the injection pressure creates more mould defects in the parts with glass fibers added. Changing the parameters makes clearly difference in the parts, thereby affecting the quality of the replications of parts.

However there is the possibility that the source of the flaws in the right side of the critical section is a mould flaw, so that the parts are damaged on its way out of the mould. Another reason for the larger amount of defects at higher injection pressure can be that the specimen is “packed” tighter in the mould. Due to the increased modulus of elasticity, as observed in the tensile strength tests, the sample will be stiffer and more resistant to exiting the mould more than if the modulus of elasticity was lower.

As a hole this experiment can not show if the quality of the part is changed, but one other way is to look at the surface roughness compared to the different kinds of pressure.

14.5 Conclusion on mould defects

Mould defects can emerge when the sample is taken out of the mould. It was observed that parts seem to have more flaws at higher injection pressure. This concludes that the parts are harder to get out of the mould because the high pressure has packed the material tight, and created large amounts of stress in the mould. The added stiffness caused by the fibers will most probably be the main cause of the higher amount of mould defects due to more resistance towards exiting the mould.

15 Surface roughness

15.1 Objective of experiment

Analysis was preformed to investigate the effects of glass fibers and various injection parameters on the surface roughness of our produced samples.

15.2 Method of analysis

The specific experiments were preformed on PEI samples from the production matrix presented in Table 10, as well as untested PS tensile bars.

The flat backside of each test sample was checked for surface roughness using an UBM Laser Scanning machine. Samples were checked on the same part of the available surface to be able to compare the results. The checked area is shown on the sketch below:

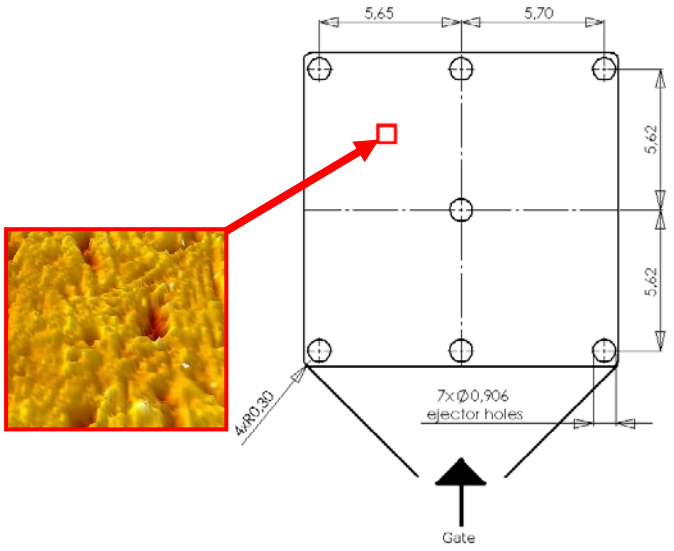


Illustration 6. Placement of scanned area on the back of sample

The scanned area measured 0,5 x 0,5 mm, and the test were performed with an accuracy of 200 dots/mm.

Measuring standards

For computation of roughness the software package Scanning Prope Image Processor SPIP was used. Surface roughness average (Sa) as defined in EUR 15178EN is the average absolute deviation of the measured surface. Sa is very much similar to roughness average (Ra). In measuring the Ra value, sampling length and assessment length are used, while in measuring Sa, sampling area and assessment area are used instead. Ra and Sa are the most commonly used parameters in surface texture analysis. Sa units are length, typically in microns.

15.3 Results

Results have been elaborated in two different sections:

1. Surface comparison between PS and PS with glass fibers (tensile bars).
2. Surface comparison between effects of injection parameters on surface roughness of PEI. Series 3-7 from Table 1.

As explained in the introduction a faulty mould heater forced us to use PEI for the comparison between parameter effects.

Complete results of the surface roughness tests are presented in appendix no. 22 Surface roughness.

From previous studies of the mould we used, we were informed, that the average surface roughness of the moulds surfaces was 0,2 [µm]. This meant that we could not expect to see an average surface roughness on our samples below 0,2 [µm].

Roughness values are presented in Table 11 below:

Sample no.	Material	Variable parameter [pressure(bar x 15)/speed (mm/s)]	Sa [µm]	Smax [µm]	Smin [µm]
1.1	PS	According to ISO3167	0,258	5,97	-1,97
1.2	PS	According to ISO3167	0,781	4,95	-8,96
1.3	PEI	900 / 77	1,57	11,6	-12,8
1.4	PEI	1500 / 88	1,36	10,4	-11,5
1.5	PEI	2100 / 95	1,10	8,99	-9,03
1.6	PEI	2400 / 105	1,19	5,02	-7,42

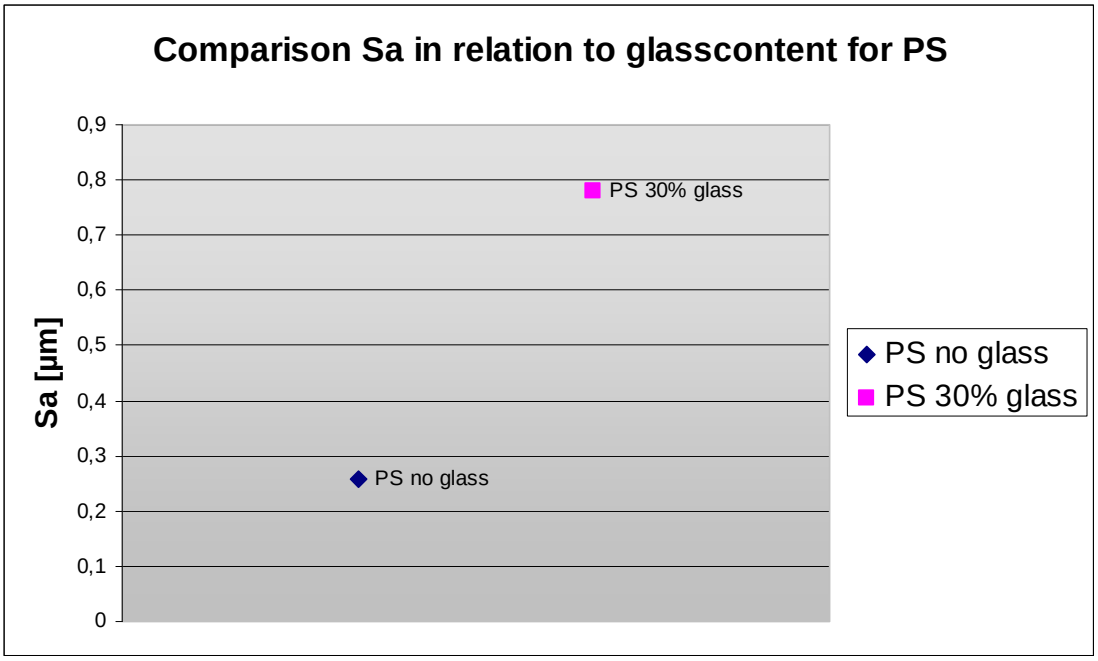
Table 12

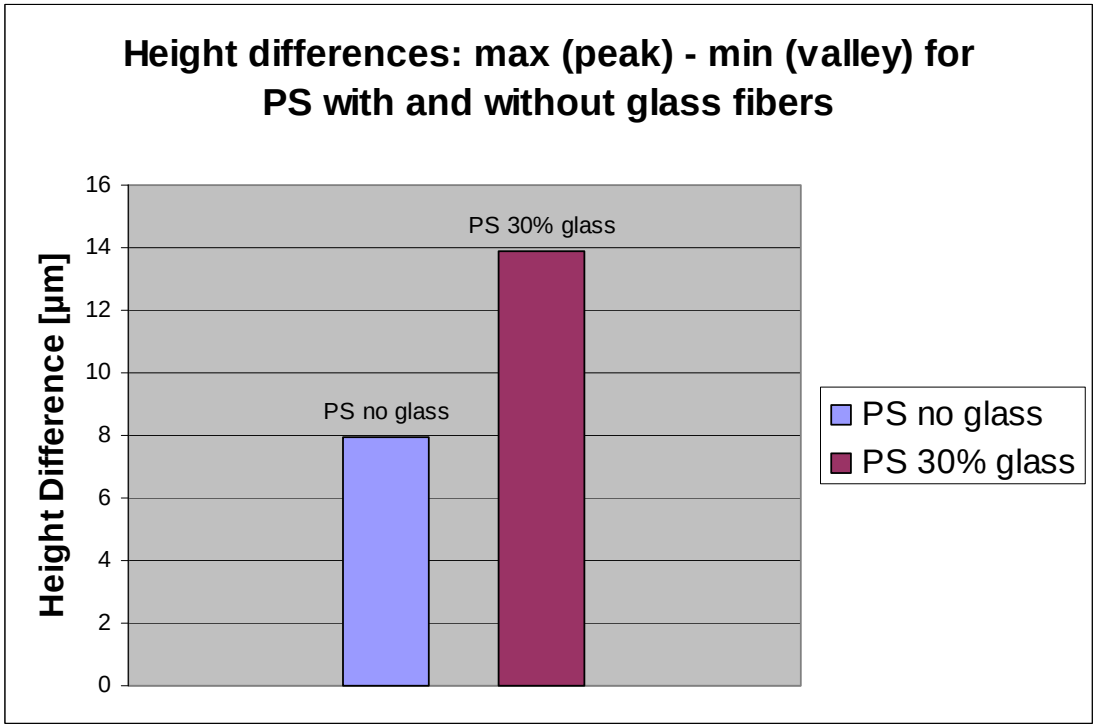
Surface comparison between PS and PS with glass fibers

The amount of samples produced for this experiment was hindered by the fact that injection moulding was not possible with PS.

These previously moulded samples had been made using the same injection parameters according to the test standard ISO3167. We only checked 2 samples. 1 with 30% glass fibers and one without fiber content. Fore more accurate results we should have checked a series of each material.

Calculated Sa values are shown on the graph below.





The results presented above show that the addition of fibers affects the surface roughness negatively. Actually the surface replication of PS without added glass is quite close to the actual surface Sa of the mould. Not only is the average roughness (Sa) increased, also the span between maximum and minimum height of the sample is increased after adding fibers. The same effect is clearly visible when comparing 3D animations of the surfaces made in SPIP:

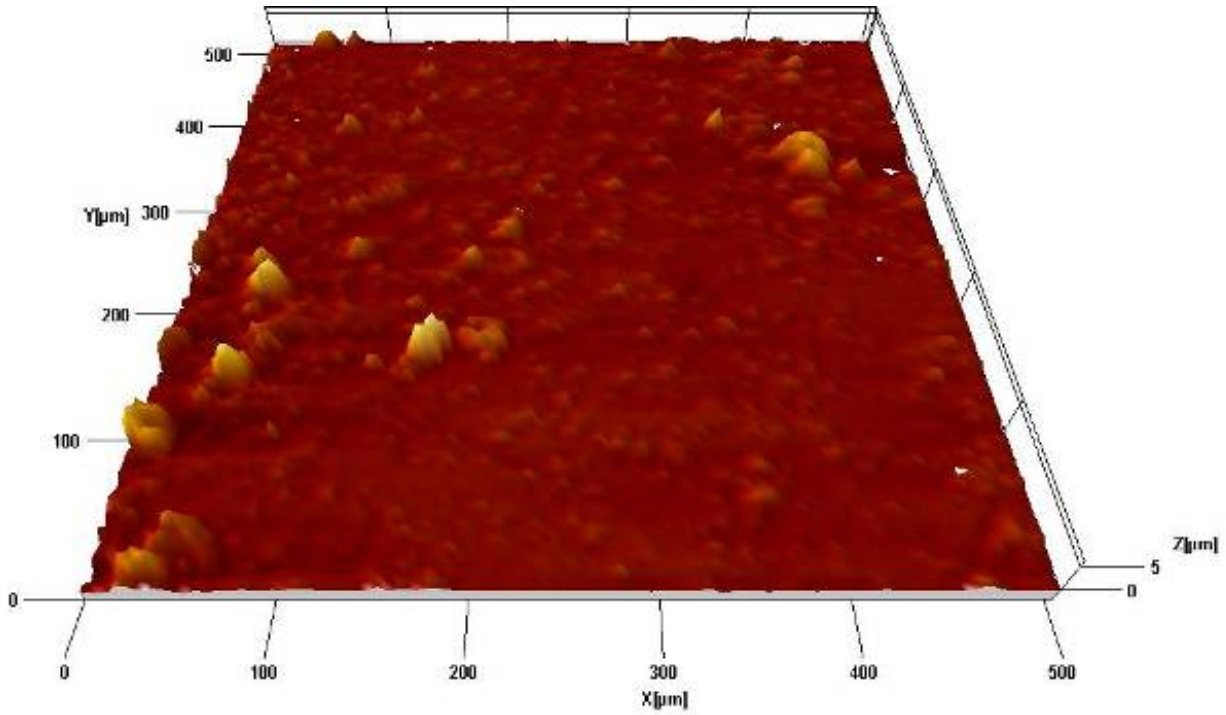


Illustration 7. 3D animation of PS surface without glass fibers added.

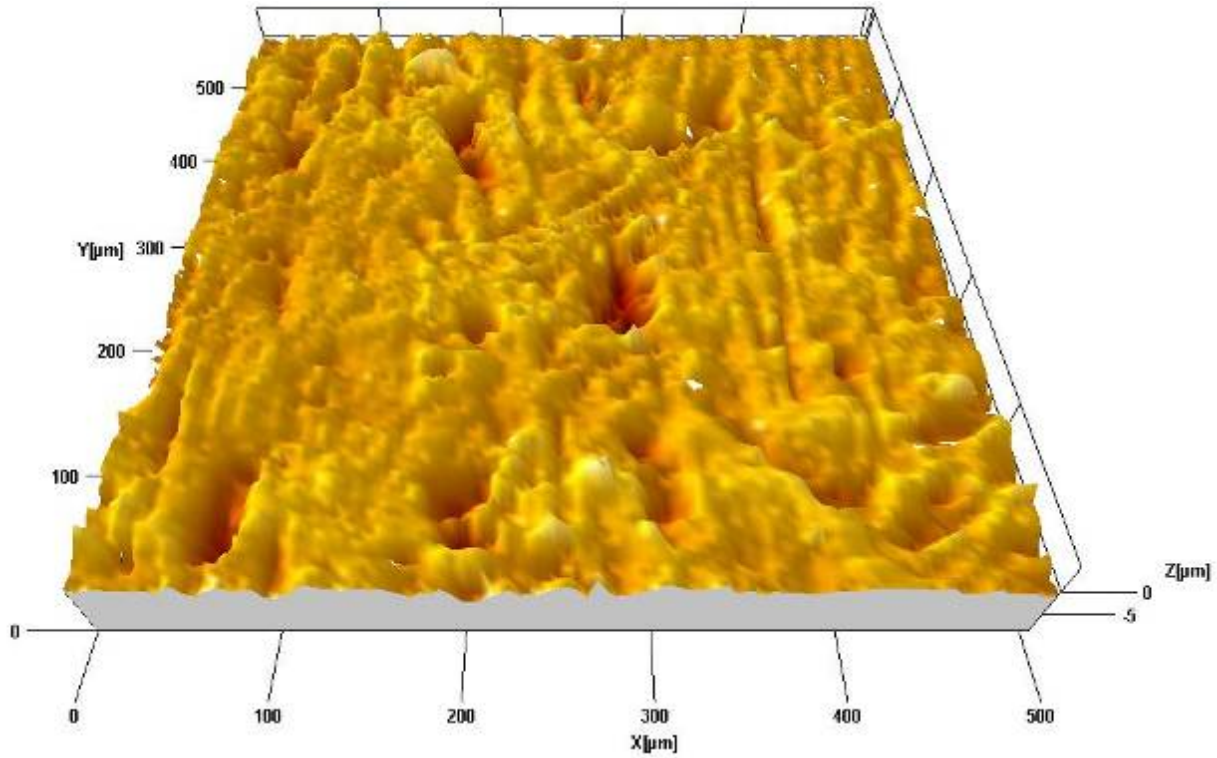
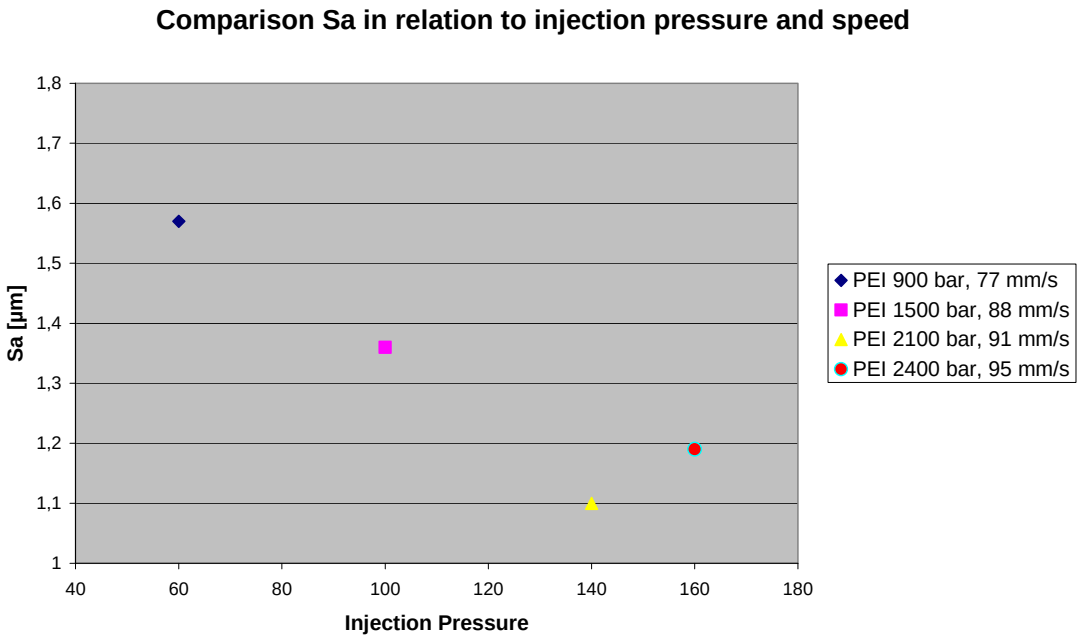
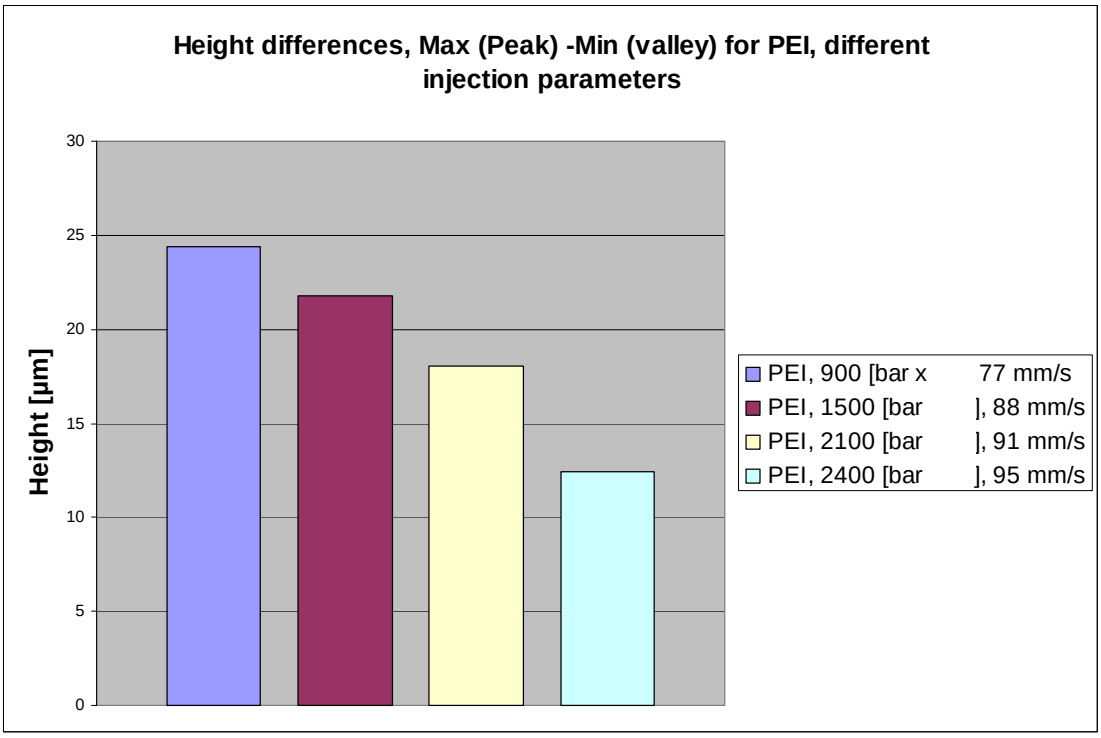


Illustration 8. 3D animation of PS surface with 30% glass fibers added.

Comparison between surface roughness and injection parameters



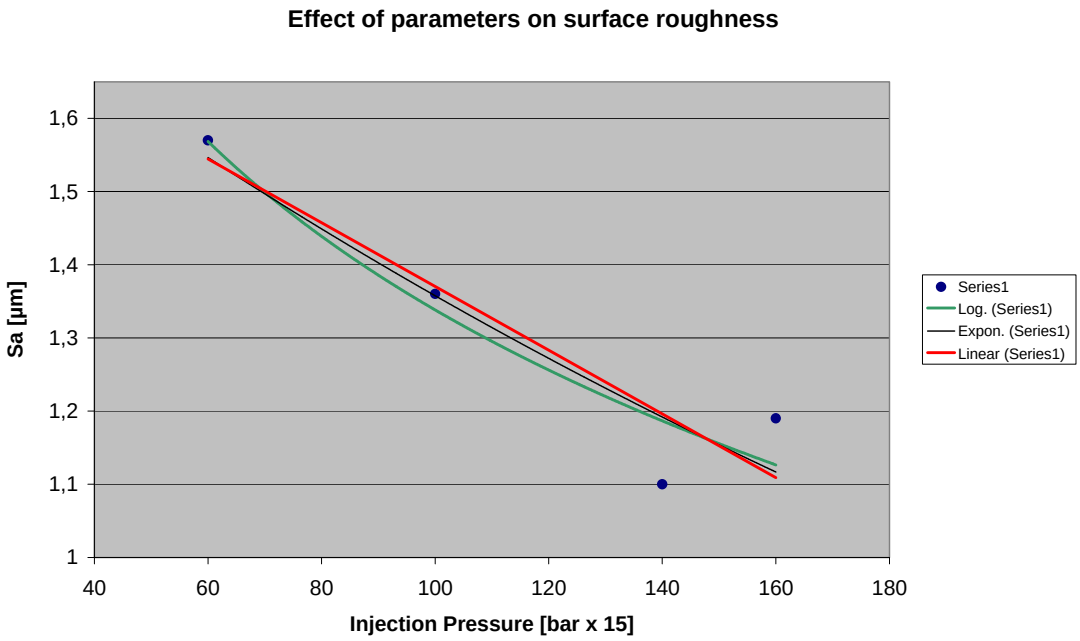


As seen by the graphs above there seems to be a resemblance between higher injection pressure, speed, and the average surface roughness. Sa diminishes as injection pressure increases', meaning the replication gets closer to that of the actual mould.

Furthermore the minimum and maximum values of the surface height are also diminished at higher injection pressure. It is possible to conclude that higher injection pressure diminishes the surface roughness.

There seems to be a linear relationship between injection pressure/speed and Sa values. Since this experiment only resulted in 4 measurements it was not possible to further investigate the exact relation.

An attempt to produce different trend lines for the relationship between pressure, speed and Sa is presented on the graph below. The relationship has been produced using linear, exponential and logarithmic equations, although the small amount of samples cannot allow us to conclude which trend line is more accurate.



The effect of better replication quality at higher pressures is also noticeable on by comparing 3d animations from SPIP.

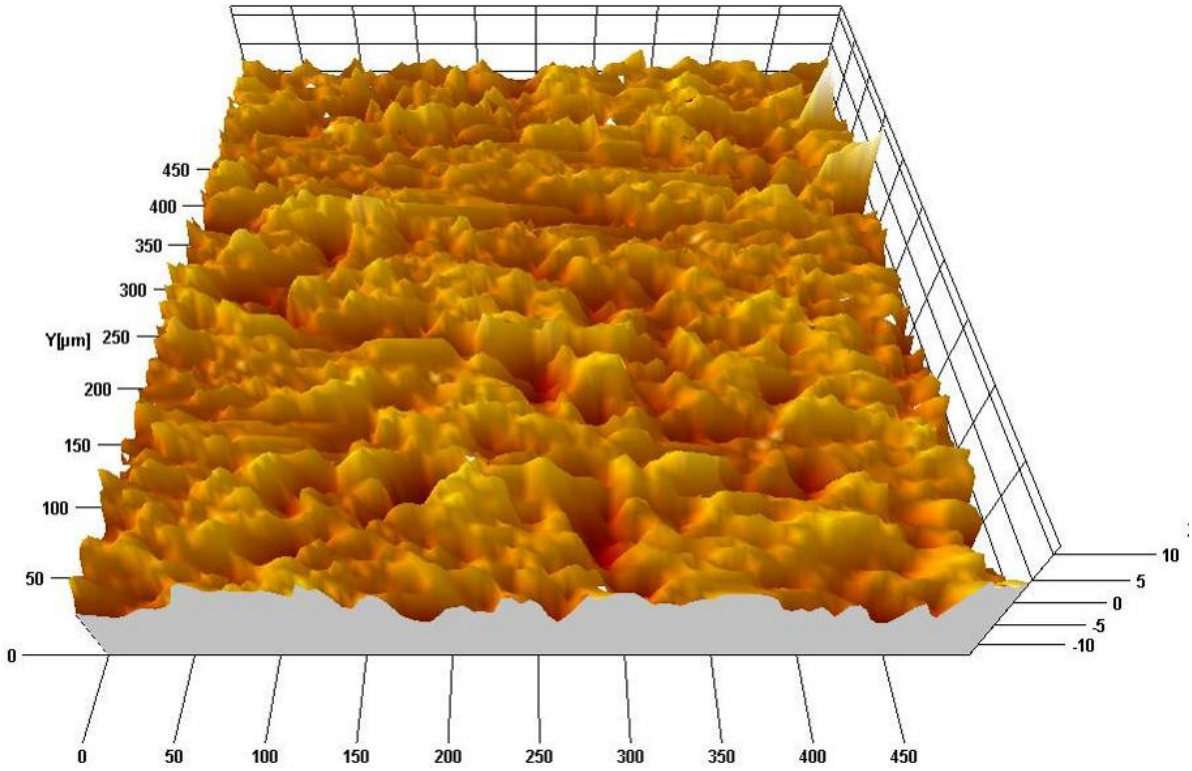


Illustration 9. 3D animation 900 bar, 77 mm/s.

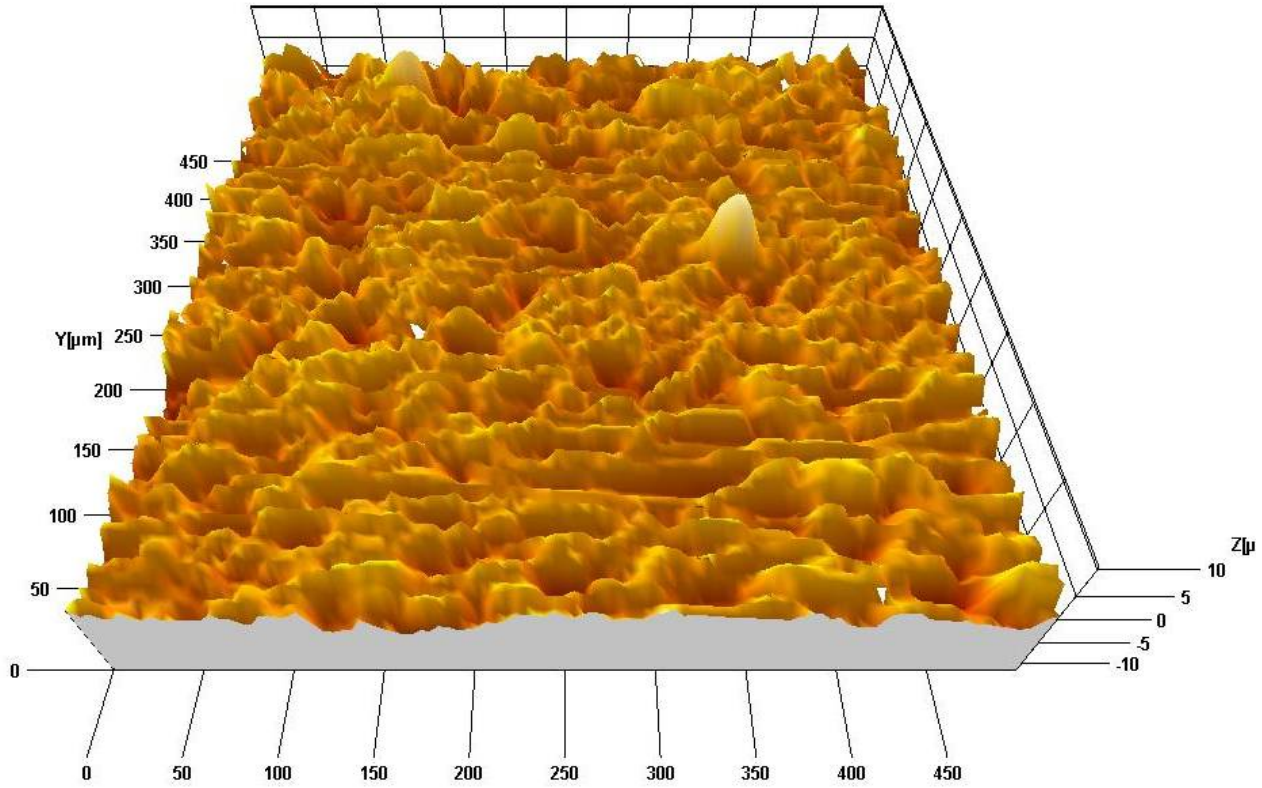


Illustration 10. 3D animation, 1500 bar, 88 mm/s

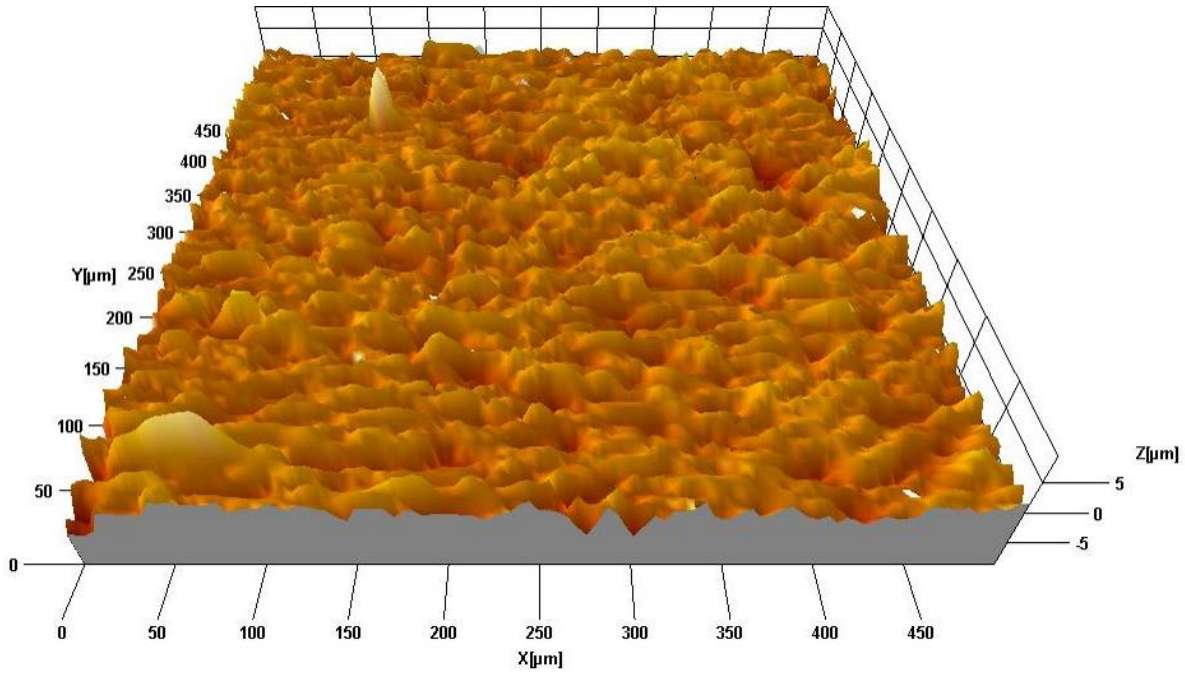


Illustration 11. 3D animation, 2100 bar, 95 mm/s.

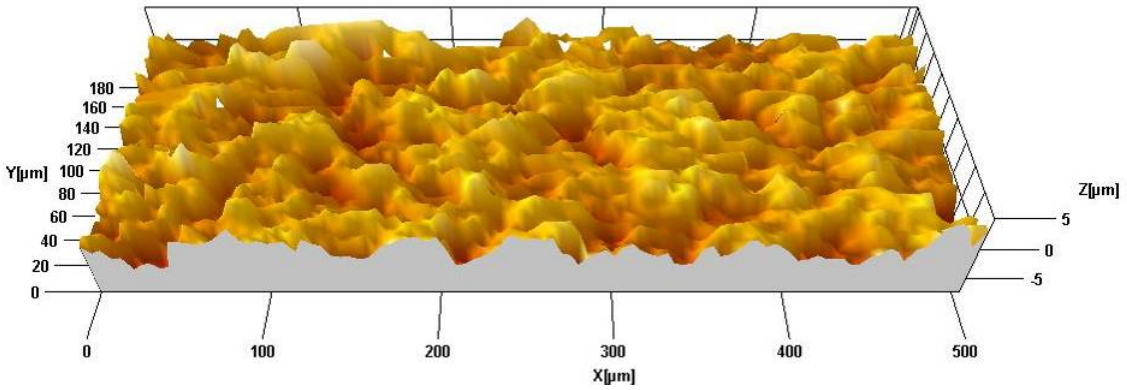


Illustration 12. 3D animation, 2400 bar, 105 mm/s

15.4 Conclusion on surface behaviour

Results of surface analysis with laser scanner have shown, that injection speed and pressure as a combined parameter effects the replication surface quality. Higher injection pressure/speed gives a better replication of the moulded surface on the sample. The surface roughness and injection pressure seems to have a linear relation in the span between 900-2400 [bar x 15].

Application of glass fibers in a melt flow will enlarge the Sa value of surface roughness for a injection moulded surface produced with PS. We found that melt flows without fibers could achieve Sa values quite close to that of the actual mould, where as Sa values for fiber composites were larger by a factor 4 compared to the Sa of the mould.

16 Chemical Analysis of distribution of fibers

16.1 Objectives of the experiment

1. To observe how the glass fibers are distributed through the moulded part

2. To observe if the geometry will effect the distribution of glass fibers in the moulded part.

The investigation will be performed on three types of samples:

5. PS granulate
6. PS granulate with 30% glass fiber
7. Moulded PS parts with 30% glass fiber

16.2 Preparation of samples

To determine the fiber distribution a chemical test was preformed on samples from the moulded PS 30% glass fiber parts.
To determine how the fibers are distributed in the moulding, from the inlet to the end of the part. Two mouldings were divided in to three pieces. Two inlet samples and one rib part geometry sample.

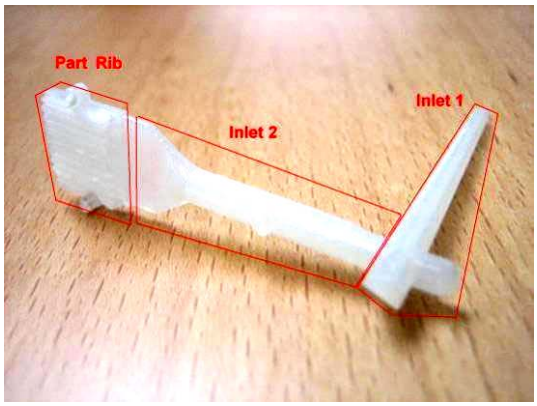


Illustration 13: Division of PS sample in 3 sections for chemical analysis.

Also to determine how the fibers were distributed through actual specimen the ribs were divided in to two areas: one sample close to the gate and one far from the gate.

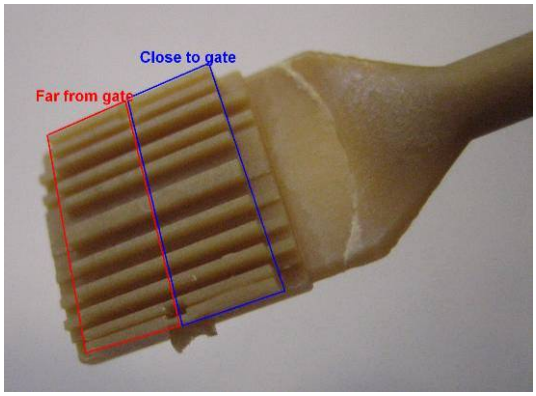


Illustration 14: Division of specimen for analysis of fiber distribution (note! this is not the actual PS sample used).

To determine if the dimensions of a rib have influence on the distribution of fibers, a thin and a thick rib was cut taken from the part.

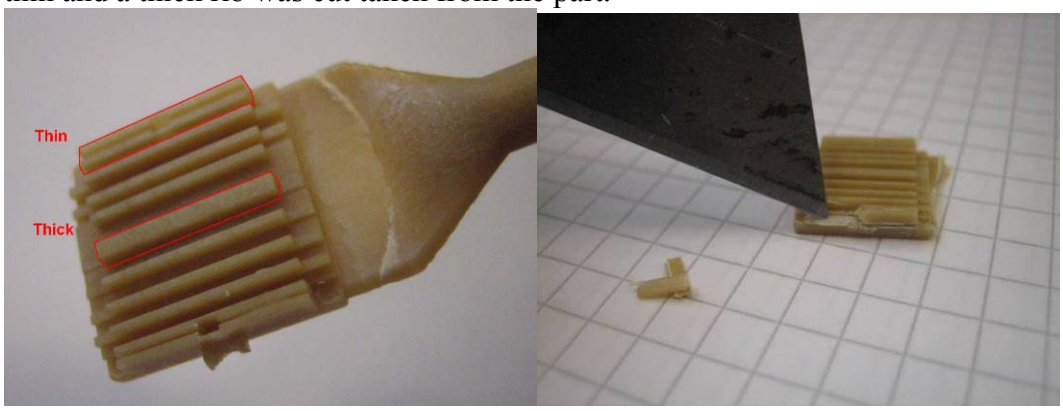


Illustration 15: Ribs removed for chemical analysis. (note! This is not the actual PS sample used).

For comparative reasons, a sample of clean PS granulate and a sample of granulate of PS with 30% glass fiber were also analyzed.

16.3 Chemical analysis method

The chosen method to determine the amount of fibers in each sample section was to first weigh each section, then dissolve the PS completely in a solvent, and then filter the fibers from the plastic using a filter paper. By comparing the amount of fibers to the weight of the original section we should be able to determine the average fiber content.

Picture 14: Scale, Dissolvant and filtering used for the chemical analysis

The original idea was to use acetone as a solvent, to test the solvent a test was made on some PS granulate without fibers. The acetone was expected to dissolve the PS quite rapidly. The dissolution of the PS proved slow, but after 24 hours the PS was dissolved.
The moulded samples with fibers was prepared with acetone, but after 24 hours a sticky mass of half dissolved PS and glass fibers was still left in the test glasses.

The acetone was deemed insufficient for completely dissolving the PS, and a harsher organic solvent was tested; Tetrahydroflouside.
The acetone was left to evaporate, and the Tetrahydroflouside was poured on to the samples, and left for 24 hours. After 24 the PS samples seemed completely dissolved.
A sample with dissolved PS granulates without fibers were used as a test for filtering through a filter: type 00H. The weight of the filtering paper was measured before and then used in a funnel The liquid with the dissolved PS and Tetrahydroflouside was then poured into the funnel and left to filter through. After further 24 hours the Tetrahydroflouside had either run through the filter or evaporated. Unfortunately not all the PS managed to filter through the paper.

16.4 Results of the chemical analysis

Complete results of the chemical analysis are presented below:

	Material	Paper	Paper + Material	Material Left	% Material of orig.
Granulate - glass	0,8664	1,0832	1,3949	0,3117	36,0
Granulate +glass	1,4944	1,097	1,7785	0,6815	45,6
Moulded part 1: 1	0,5635				
2	0,4573				
Rib	0,4812				
Moulded part 2: 1	0,5542	1,0877	1,363	0,2753	49,7
2	0,4603	1,0815	1,2817	0,2002	43,5
Rib	0,4657	1,0827	1,3101	0,2274	48,8
Close to gate	0,2307	1,0869	1,1836	0,0967	41,9
Far from gate	0,2209	1,0898	1,1976	0,1078	48,8
Thick rib	0,0267	1,0906	1,1077	0,0171	64,0
Thin rib	0,0362	1,0965	1,1224	0,0259	71,5

Table 13: Results of chemical analysis

16.5 Discussion on chemical analysis

In the Table 14 the results from the chemical test are shown. The reference samples: one sample with clean PS granulate and one sample of PS granulate with glass fiber was dissolved in the Tetrahydroflouside. The sample with Clean PS indicates that not all the PS is filtered through the paper filter. Unfortunately about 35% of the material is still left in the filter!
The granulate with fibers is suppose to have a fiber content of 30% based on weight. In the diagram it shows that 45% of the material is left in the filter. If 30% of the weight consists of fibers, the remaining 15% has to be undissolved PS. This also indicates that the amount of PS that stays in the filter is not fixed at 35%, but fluctuates.

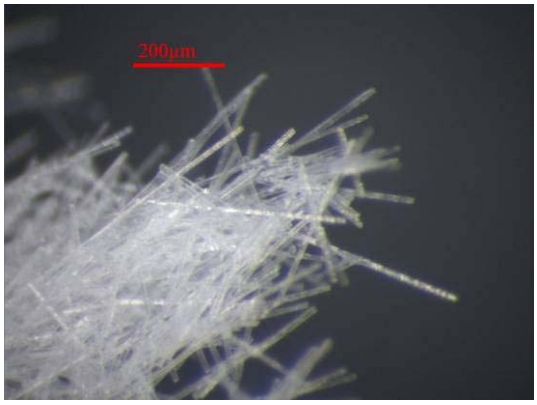
16.6 Conclusion on chemical analysis

If we look at the rest of the results, it appears to be likely that the difference in the amount of fibers left is due to uncertainties and errors concerning the test method. In the light of the results from the reference samples it is hard to trust the numbers of the diagram, and the chemical tests in fact proved more or less useless.

Some of the factor there can have influenced the results are.

- The amount of solvent, can have something to say about how much of the PS will go through the filter, amount of PS left in the filter was not stable.
- The filter can absorb humidity from the air and that make a difference on the weight.
- Some of the fibers and PS can be left in the test glass.

On the pictures fibers from one of the samples are clothing together, this is possible because of the undissolved PS.



Picture 15: Clothing of fibers due to undissolved PS

17 Inspection of fibers using LOM C

17.1 Objectives of the experiment

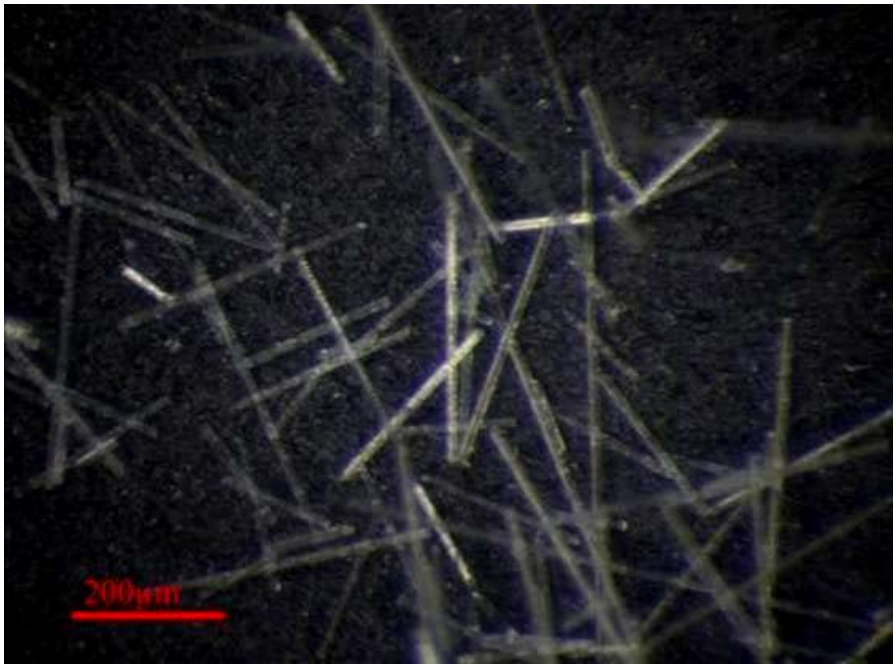
- To investigate if glass fibers change length due to stress during moulding.

17.2 Method

Measurement of fiber length from different sections of the test specimen. Fibers are obtained from the chemical analysis and analyzed using LOM C microscope.

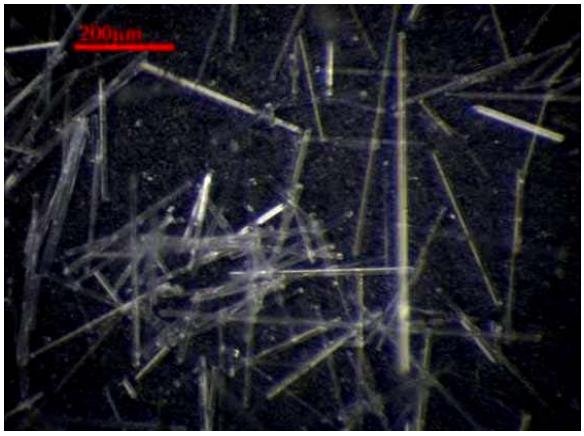
17.3 Results of inspection

By comparing the fibers from granulate and fibers from the moulded parts it is possible to se if the length of the glass fibers change during injection moulding. It could be expected that fibers would break when they are pushed in to the mould, but when we look at the pictures we observe that the fibers are approximately the same length in all of the samples:
Picture of the fibers from granulates. The fibers are measured to have an approximate length between 600µm-200µm long.



Picture 16: Fibers from PS granulate 30% fibers

In the sample of the rib section close to the gate the fibers are about 800µm-200µm in length.

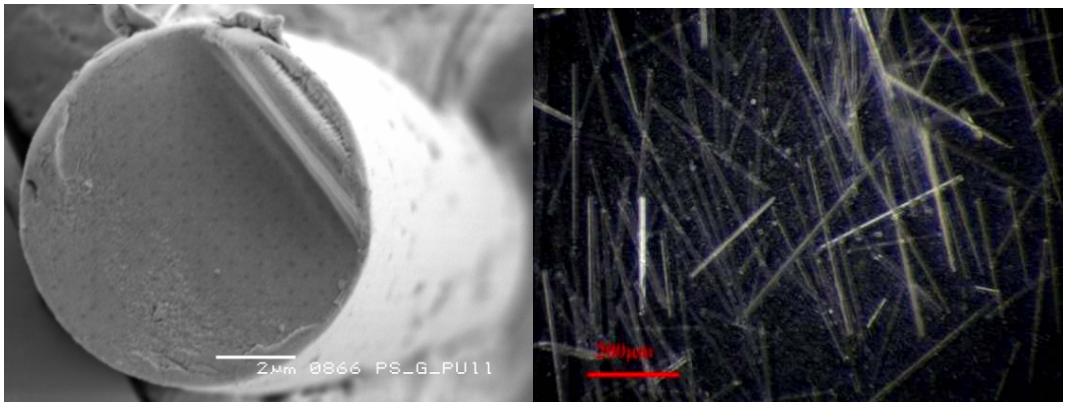


Picture 17: Fibers from moulded part close to the gate

In the sample from the thin rib the fibers are about 600µm-100µm long.

Picture 18: Fibers from the thin rib

It dos not seem like the fibers are damaged when they are moulded. If this was the case, we would expect an increasing amount of small fibers in the two last pictures presented above. On the other hand there is a statistical insecurity related to observing samples, as this only pictures a small section of the actual area we wish to investigate.



Picture 19: Fiber from tensile test and fibers from the thin rib

From the pictures of the fibers we estimate that the fibers to have a diameter of Ø10 µm and a length of 200-600µm

18 Cross sectional analysis of fiber direction and distribution

18.1 Objectives of the experiment

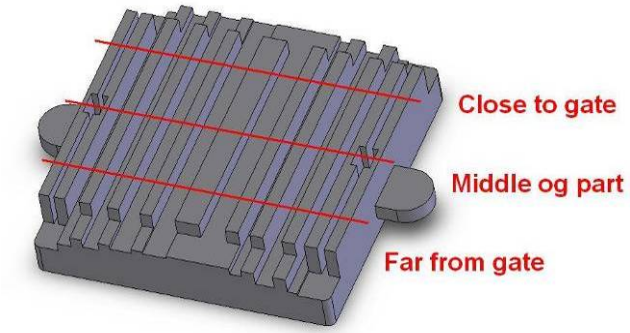
1. To observe how the glass fibers are distributed in three cross sections of the part.
2. To observe if the geometry will effect the distribution of fibers.
3. To observe the direction of the fibers in different cross section of the part.

The investigation will be performed on three samples:

1. Cross section close to the gate
2. Cross section in the middle
3. Cross section close far from the gate

18.2 Preparation of samples

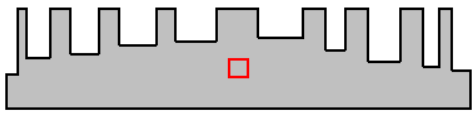
By looking at three cross sections through the test specimen we decided to investigate the amount of fibers and their direction. The specimen was cut in one section close to the gate, one far from the gate and one in the middle where the critical section is placed. Each sample was grinded and investigated under a LOM E microscope.



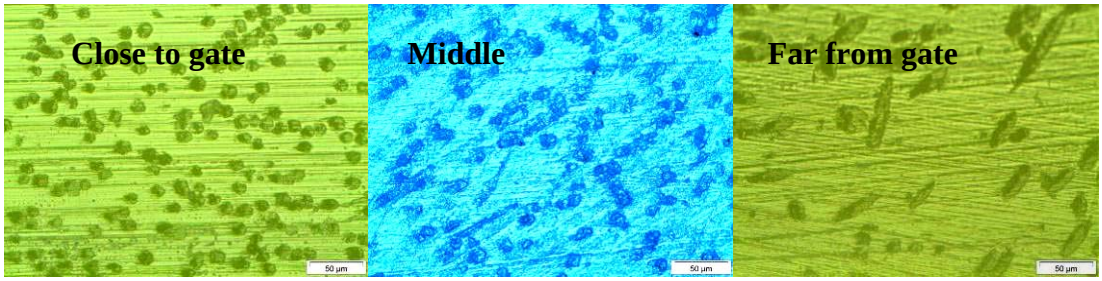
Picture 20: Part with three cross sections

18.3 Result on fiber direction

In the following we look at pictures taken from right under the thickest rib (see Picture 21) this is the thickest part, the picture size are 325µm x 250µm.



Picture 22: Cross section of the part, marks where the pictures are taken



Picture 23: Comparison of cross sections under thick rib

From Picture 24 it is clear, that there is a difference in the amount of fibers in the three cross sections, since pictures all have the same size and resolution. In the pictures there is respectively: 166, 88 and 41 fibers. It seems likely that the further from the gate you get the smaller amount of fibers. The distribution of fibers through the part seems to have an exponential relation. However with only 3 samples the actual relationship can not be verified.

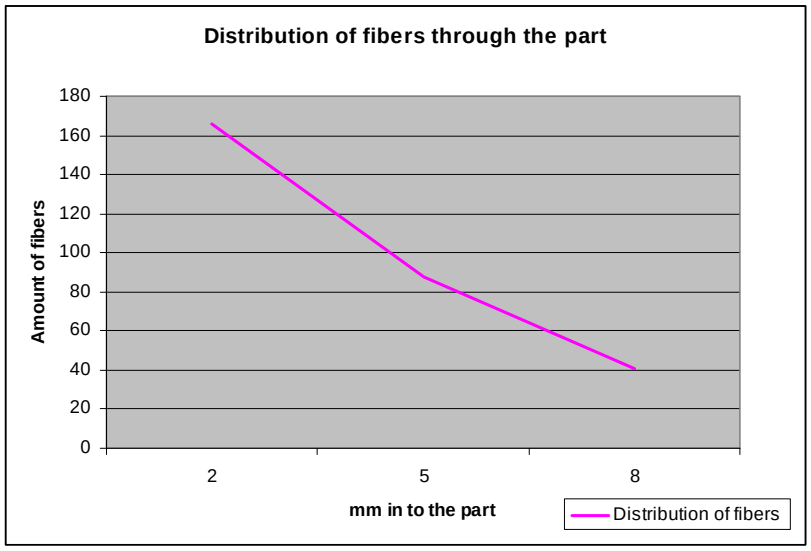
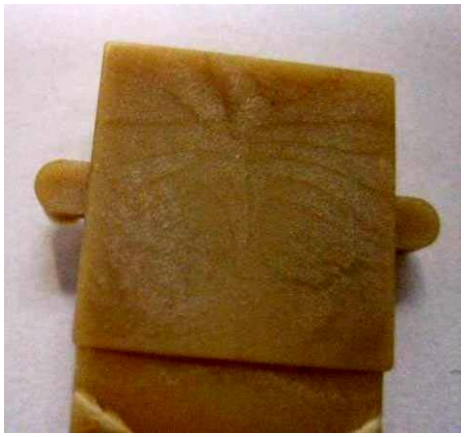


Table 15: Distribution of fibers through the part

There is also a difference in the direction of the fibers. Close to the gate the fibers are oriented along the longitudinal direction of the initial flow. Far from the gate the fibers are more unorganized.
When we look at a picture of a part it is possible to how the mould is filled and why the fiber orientation is like on the pictures.

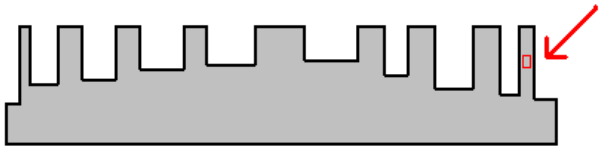


Picture 25: Part with lines from filling

The mould fills from the gate and packaging lines are clearly visible at the end of the part.

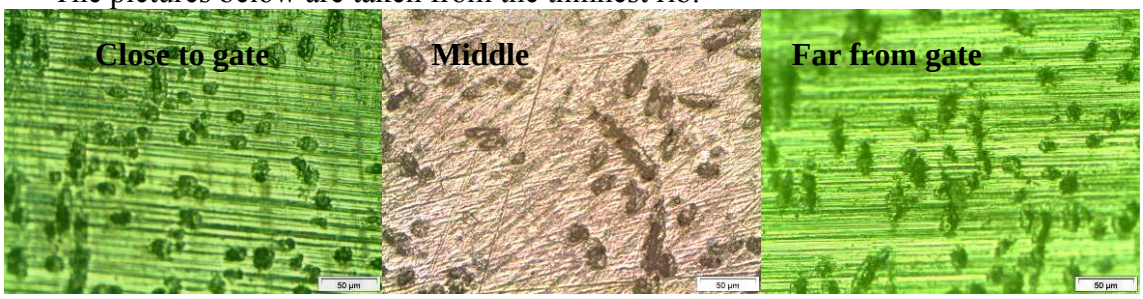
The thin rib

To investigate the influence of micro geometry, the cross section of the thinnest rib was investigated.



Picture 26: Cross section of the part, marks where the pictures are taken

The pictures below are taken from the thinnest rib.

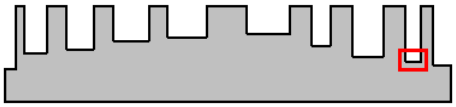


Picture 27: Microscope pictures of cross sections, thin rib

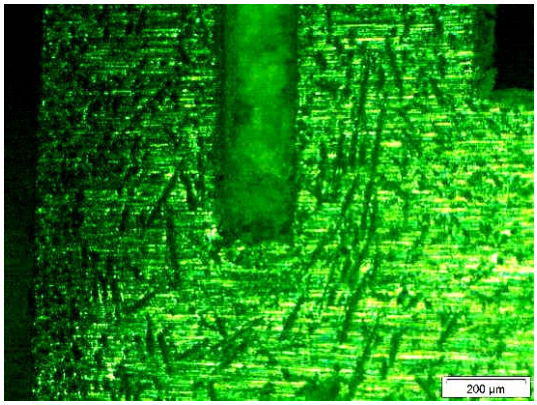
There is still a difference, in the amount of fibers, between the three cross sections, but the amount of fibers is much smaller in the thin rib than under the thick rib, only 77, 61 and 50 fibers, even though area and resolution is the same. The direction of the fibers is still in the flow direction close to the gate and more unorganized when you get fare away from the gate, but not as striking as on the previous pictures.

If looked upon the pictures of the programmed moulding the thin rib is filled from both sides, this can be the reason why the difference in direction is smaller.
The smaller amount of fibers in the thin rib proves that the geometry have an effect on the distribution of the fibers.

Distribution around corners



Picture 28: Cross section of the part, marks where the pictures are taken



Picture 29: Microscope picture of cross sections, corner of thin rib, far from gate

In the cross section far from the gate, the fibers are a bit unorganized like mention before, but around the corners the fibers lay in the opposite direction this result from turbulence in the filling.

Injection speed

The injection speed has an influence on how the fibers are directed.
At high injection speeds, the fiber will be oriented parallel to the flow direction on the surfaces, while in the centre of the moulds cross section they are oriented perpendicular to the flow direction. With increasing injection speed, surface layer thickness increases. At low injection speeds, the fibers are oriented at the flow direction and the thickness of the centre constitutes more than half of product thickness. At low injection speeds the surfaces become almost fiber free.
[Experimental investigation of the effect of glass fibers on the mechanical properties of polypropylene (PP) and polyamide 6 (PA6) plastics]

18.4 Conclusion on fiber distribution

Even though the chemical test did not show a big difference in the amount of fibers between close to and far from the gate, in the view of the pictures it seams likely that there is a smaller amount of fibers fare from the gate than close to.

Even though the fibers are wary small compared to the ribs, the geometry have an effect on the filling, the fibers have difficulties getting in to the thinnest ribs. In the case of micro moulding we can not rely on the fiber getting evenly distributed.

The direction of the fibers is dependent on the injection speed and where in the part one look. The vortex that occurs in the far end from the gate swirl the fibers around. At the same time the injection speed determine at the direction the cross section close to the gate.

19 General Conclusions

Summarized conclusions can be made on following points based on the studies presented in this report. Please note that the conclusions are only valid for the specific polymer materials used, and parameter changes presented in the studies.

Based on investigations of the critical area of the moulded specimens, it can be conclude that in general concerning micro structures, either tollerancewise or geometrically it is preferable to use polymers without glass fibers if a demand for good replication quality is present.

The work with the injection moulding have shown that PEI as a polymer is much better suited to micro moulding with high tolerances than PS, due to the higher strength and flow temperature of the PEI, as well as the brittle nature of PS.

The investigation of surface roughness and geometrical defects has proved that injection parameters for PEI need to be tailored to fit the specific demands of the micro moulded parts. In the specific case it was found that higher injection pressure/speed diminished the surface roughness of PEI samples, where as moulding defects were minimal at lower injection pressures/speed.

The addition of glass fibers to the injection moulding melt will cause the material to get stiffer (higher modulus of elasticity), and increase the maximum yield strength of the compound. The added stiffness affects the materials ability to eject from the mould without creating permanent defects on the specimen.

20 Appendix

20.1 Data sheet PS 158K

Polystyrol 158 K | PS | BASF - 2007-02-08

Polystyrol 158 K is a heat resistant, rapid freezing general purpose grade. It is suitable for expanded sheet and film; for blends with high
impact Polystyrol in heat contact applications, for transparent, resistant applications in blends with Styrolux.

Rheological properties	**Value**	**Unit**	**Test Standard**
Melt volume-flow rate	**3**	cm³/10min	ISO 1133
Temperature	**200**	°C	ISO 1133
Load	**5**	kg	ISO 1133

Mechanical properties	**Value**	**Unit**	**Test Standard**
Tensile Modulus	**3300**	MPa	ISO 527-1/-2
Stress at break	**55**	MPa	ISO 527-1/-2
Strain at break	**3**	%	ISO 527-1/-2
Tensile creep modulus (1h)	**3300**	MPa	ISO 899-1
Tensile creep modulus (1000h)	**2600**	MPa	ISO 899-1
Charpy notched impact strength (+23°C)	**3**	kJ/m²	ISO 179/1eA

Thermal properties	**Value**	**Unit**	**Test Standard**
Glass transition temperature (10°C/min)	**100**	°C	ISO 11357-1/-2
Temp. of deflection under load (1.80 MPa)	**86**	°C	ISO 75-1/-2
Temp. of deflection under load (0.45 MPa)	**98**	°C	ISO 75-1/-2
Vicat softening temperature (50°C/h 50N)	**101**	°C	ISO 306
Coeff. of linear therm. expansion (parallel)	**0.8**	E-4/°C	ISO 11359-1/-2
Burning Behav. at 1.5 mm nom. thickn.	**HB**	class	IEC 60695-11-10
Thickness tested	**1.5**	mm	IEC 60695-11-10
UL recognition	**UL**	-	-
Burning Behav. at thickness h	**HB**	class	IEC 60695-11-10
Thickness tested	**3.2**	mm	IEC 60695-11-10
UL recognition	**UL**	-	-
Oxygen index	**18**	%	ISO 4589-1/-2

Electrical properties	**Value**	**Unit**	**Test Standard**
Relative permittivity (100Hz)	**2.5**	-	IEC 60250
Relative permittivity (1 MHz)	**2.5**	-	IEC 60250
Dissipation factor (100 Hz)	**0.9**	E-4	IEC 60250
Dissipation factor (1 MHz)	**0.5**	E-4	IEC 60250
Comparative tracking index	**425**	-	IEC 60112

Other properties	**Value**	**Unit**	**Test Standard**
Density	**1050**	kg/m³	ISO 1183

Material specific properties	**Value**	**Unit**	**Test Standard**
Viscosity number	**96**	cm³/g	ISO 307, 1157, 1628

Test specimen production	**Value**	**Unit**	**Test Standard**
Injection Molding, melt temperature	**230**	°C	ISO 294
mold temperature	**40**	°C	ISO 10724
injection velocity	**200**	mm/s	ISO 294

Rheological calculation properties	Value	Unit	Test Standard
Density of melt	**936**	kg/m³	-
Thermal conductivity of melt	**0.155**	W/(m K)	-
Spec. heat capacity melt	**2300**	J/(kg K)	-
Ejection temperature	**96**	°C	-

Multi-point data

Characteristic

Regional Availability
North America; Europe; Asia Pacific; South and Central America; Near East/Africa; India

Processing
Injection Molding; Film Extrusion; Profile Extrusion; Sheet Extrusion; Other Extrusion

Delivery Form
Pellets

Special Characteristics
Transparent

Processing

Injection Molding

PROCESSING
injection molding, Melt temperature, range: 180 - 280 °C
injection molding, Melt temperature, recommended: 230 °C
injection molding, Mold temperature, range: 10 - 60 °C
injection molding, Mold temperature, recommended: 40 °C

Polystyrol 158 K can be injection molded at temperatures between 180 and 280°C.Recommended mold temperatures are between 10 and 60°C.

Film Extrusion

PROCESSING
Extrusion, Blown film, Melt temperature: 180 - 210 °C
Extrusion, Flat film, Melt temperature: 200 - 240 °C

Extrusion melt temperature should not exceed 240°C.

Other Extrusion

PROCESSING
Extrusion, Pipes, Melt temperature: 180 - 210 °C

Profile Extrusion

PROCESSING
Extrusion, Profiles, Melt temperature: 210 °C

Sheet Extrusion

PROCESSING
Extrusion, Plates, Melt temperature: 200 - 230 °C

20.2 Data sheet PEI without glass fibers

Ultem* Resin 1000
Americas: COMMERCIAL

Transparent, standard flow Polyetherimide (Tg 217C). ECO Conforming, UL94 V0 and 5VA listing. US FDA and EU Food Contact compliant, NSF 51 listing,
ISO 10993 compliant in natural color.

TYPICAL PROPERTIES [1] TYPICAL VALUE UNIT STANDARD

MECHANICAL

Tensile Stress, yld, Type I, 5 mm/min 110 MPa ASTM D 638
Tensile Strain, yld, Type I, 5 mm/min 7 % ASTM D 638
Tensile Strain, brk, Type I, 5 mm/min 60 % ASTM D 638
Tensile Modulus, 5 mm/min 3580 MPa ASTM D 638
Flexural Stress, yld, 2.6 mm/min, 100 mm span 165 MPa ASTM D 790
Flexural Modulus, 2.6 mm/min, 100 mm span 3510 MPa ASTM D 790
Hardness, Rockwell M 109 - ASTM D 785
Taber Abrasion, CS-17, 1 kg 10 mg/1000cy ASTM D 1044

IMPACT

Izod Impact, unnotched, 23°C 1335 J/m ASTM D 4812
Izod Impact, notched, 23°C 53 J/m ASTM D 256
Izod Impact, Reverse Notched, 3.2 mm 1335 J/m ASTM D 256
Gardner, 23°C 36 J ASTM D 3029

THERMAL

Vicat Softening Temp, Rate B/50 218 °C ASTM D 1525
HDT, 0.45 MPa, 6.4 mm, unannealed 210 °C ASTM D 648
HDT, 1.82 MPa, 6.4 mm, unannealed 201 °C ASTM D 648
CTE, -20°C to 150°C, flow 5.58E-05 1/°C ASTM E 831
CTE, -20°C to 150°C, xflow 5.4E-05 1/°C ASTM E 831
Thermal Conductivity 0.22 W/m-°C ASTM C 177
Relative Temp Index, Elec 170 °C UL 746B
Relative Temp Index, Mech w/impact 170 °C UL 746B
Relative Temp Index, Mech w/o impact 170 °C UL 746B

PHYSICAL

Specific Gravity 1.27 - ASTM D 792

Source, GMD, Last Update:04/14/2003

1) Typical values only. Variations within normal tolerances are possible for variose colours.All values are measured at least after 48 hours storage at 230C/50% relative humidity.
All properties, expect the melt volume rate are measured on injection moulded samples.
All samples are prepared according to ISO 294.
2) Only typical data for material selection purpose.Not to be used for part or tool design.
3) This rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.
4) Own measurement according to UL.

Ultem* Resin 1000
Americas: COMMERCIAL

TYPICAL PROPERTIES [1] TYPICAL VALUE UNIT STANDARD

PHYSICAL
Specific Gravity 1.27 - ASTM D 792
Water Absorption, 24 hours 0.25 % ASTM D 570
Water Absorption, equilibrium, 23C 1.25 % ASTM D 570
Mold Shrinkage, flow, 3.2 mm 0.5 - 0.7 % GE Method
Melt Flow Rate, 337°C/6.6 kgf 9 g/10 min ASTM D 1238
Poisson's Ratio 0.3 - ASTM D 638
ELECTRICAL
Volume Resistivity 1.E+17 Ohm-cm ASTM D 257
Dielectric Strength, in air, 1.6 mm 32.7 kV/mm ASTM D 149
Dielectric Strength, in oil, 1.6 mm 27.9 kV/mm ASTM D 149
Dielectric Strength, in oil, 3.2 mm 19.6 kV/mm ASTM D 149
Relative Permittivity, 100 Hz 3.15 - ASTM D 150
Relative Permittivity, 1 kHz 3.15 - ASTM D 150
Dissipation Factor, 100 Hz 0.0015 - ASTM D 150
Dissipation Factor, 1 kHz 0.0012 - ASTM D 150
Dissipation Factor, 2450 MHz 0.0025 - ASTM D 150
Arc Resistance, Tungsten {PLC} 5 PLC Code ASTM D 495
Hot Wire Ignition {PLC) 1 PLC Code UL 746A
High Voltage Arc Track Rate {PLC} 2 PLC Code UL 746A
High Ampere Arc Ign, surface {PLC} 3 PLC Code UL 746A
Comparative Tracking Index (UL) {PLC} 4 PLC Code UL 746A
FLAME CHARACTERISTICS
CSA (See File for complete listing) LS88480 File No. CSA LISTED
Oxygen Index (LOI) 47 % ASTM D 2863
NBS Smoke Density, Flaming, Ds 4 min 0.7 - ASTM E 662
Source, GMD, Last Update:04/14/2003

1) Typical values only. Variations within normal tolerances are possible for variose colours.All values are measured at least after 48 hours storage at 230C/50% relative humidity.
All properties, expect the melt volume rate are measured on injection moulded samples.
All samples are prepared according to ISO 294.
2) Only typical data for material selection purpose.Not to be used for part or tool design.
3) This rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.
4) Own measurement according to UL.

Ultem* Resin 1000

Americas: COMMERCIAL

PROCESSING PARAMETERS TYPICAL VALUE UNIT

Injection Molding

Drying Temperature 150 °C
Drying Time 4 - 6 hrs
Drying Time (Cumulative) 24 hrs
Maximum Moisture Content 0.02 %
Melt Temperature 350 - 400 °C
Nozzle Temperature 345 - 400 °C
Front - Zone 3 Temperature 345 - 400 °C
Middle - Zone 2 Temperature 340 - 400 °C
Rear - Zone 1 Temperature 330 - 400 °C
Mold Temperature 135 - 165 °C
Back Pressure 0.3 - 0.7 MPa
Screw Speed 40 - 70 rpm
Shot to Cylinder Size 40 - 60 %
Vent Depth 0.025 - 0.076 mm

Extrusion Blow Molding

Drying Temperature 140 - 150 °C
Drying Time 4 - 6 hrs
Drying Time (Cumulative) 24 hrs
Maximum Moisture Content 0.01 - 0.02 %
Melt Temperature (Parison) 320 - 355 °C
Barrel - Zone 1 Temperature 325 - 350 °C
Barrel - Zone 2 Temperature 330 - 355 °C
Barrel - Zone 3 Temperature 330 - 355 °C

Barrel - Zone 4 Temperature 330 - 355 °C
Adapter - Zone 5 Temperature 330 - 355 °C
Head - Zone 6 - Top Temperature 330 - 355 °C
Head - Zone 7 - Bottom Temperature 330 - 355 °C
Screw Speed 10 - 70 rpm
• DO NOT purge with low melting styrene or acrylic resins.
• Up to 30% Regrind has been successfully reprocessed.
Source, GMD, Last Update:04/14/2003

1) Typical values only. Variations within normal tolerances are possible for variose colours.All values are measured at least after 48 hours storage at 230C/50% relative humidity.
All properties, expect the melt volume rate are measured on injection moulded samples.
All samples are prepared according to ISO 294.
2) Only typical data for material selection purpose.Not to be used for part or tool design.
3) This rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.
4) Own measurement according to UL.

Ultem* Resin 1000
Americas: COMMERCIAL

20.3 Data sheet PEI with 30% glass fibers

Ultem* Resin 2312EPR
Europe-Africa-Middle East: COMMERCIAL

30% Milled glass filled, high flow Polyetherimide (Tg 217C) with internal mold release and enhanced electroplatability. ECO Conforming, UL94 V0 listing.

TYPICAL PROPERTIES [1] TYPICAL VALUE UNIT STANDARD

MECHANICAL

Tensile Stress, yld, Type I, 5 mm/min 94 MPa ASTM D 638
Tensile Stress, brk, Type I, 5 mm/min 94 MPa ASTM D 638
Tensile Strain, yld, Type I, 5 mm/min 2 % ASTM D 638
Tensile Strain, brk, Type I, 5 mm/min 2 % ASTM D 638
Tensile Modulus, 5 mm/min 6480 MPa ASTM D 638
Flexural Stress, yld, 1.3 mm/min, 50 mm span 156 MPa ASTM D 790
Flexural Modulus, 1.3 mm/min, 50 mm span 5580 MPa ASTM D 790
Tensile Stress, yield, 5 mm/min 80 MPa ISO 527
Tensile Stress, break, 5 mm/min 80 MPa ISO 527
Tensile Strain, yield, 5 mm/min 2 % ISO 527
Tensile Strain, break, 5 mm/min 2 % ISO 527
Tensile Modulus, 1 mm/min 5300 MPa ISO 527
Flexural Stress, yield, 2 mm/min 145 MPa ISO 178
Flexural Modulus, 2 mm/min 5500 MPa ISO 178

IMPACT

Izod Impact, unnotched, 23°C 330 J/m ASTM D 4812
Izod Impact, notched, 23°C 39 J/m ASTM D 256
Instrumented Impact Total Energy, 23°C 15 J ASTM D 3763
Izod Impact, unnotched 80*10*4 +23°C 25 kJ/m² ISO 180/1U
Izod Impact, unnotched 80*10*4 -30°C 25 kJ/m² ISO 180/1U
Izod Impact, notched 80*10*4 +23°C 5 kJ/m² ISO 180/1A
Izod Impact, notched 80*10*4 -30°C 5 kJ/m² ISO 180/1A
Charpy 23°C, V-notch Edgew 80*10*4 sp=62mm 5 kJ/m² ISO 179/1eA
Charpy -30°C, V-notch Edgew 80*10*4 sp=62mm 4 kJ/m² ISO 179/1eA
Charpy 23°C, Unnotch Edgew 80*10*4 sp=62mm 25 kJ/m² ISO 179/1eU
Charpy -30°C, Unnotch Edgew 80*10*4 sp=62mm 25 kJ/m² ISO 179/1eU

Source, GMD, Last Update:03/30/2004

1) Typical values only. Variations within normal tolerances are possible for variose colours.All values are measured at least after 48 hours storage at 230C/50% relative humidity.
All properties, expect the melt volume rate are measured on injection moulded samples.
All samples are prepared according to ISO 294.
2) Only typical data for material selection purpose.Not to be used for part or tool design.
3) This rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.
4) Own measurement according to UL.

Ultem* Resin 2312EPR
Europe-Africa-Middle East: COMMERCIAL

TYPICAL PROPERTIES [1] TYPICAL VALUE UNIT STANDARD

IMPACT

Charpy -30°C, Unnotch Edgew 80*10*4 sp=62mm 25 kJ/m² ISO 179/1eU

THERMAL

Vicat Softening Temp, Rate B/50 216 °C ASTM D 1525
HDT, 0.45 MPa, 3.2 mm, unannealed 204 °C ASTM D 648
HDT, 1.82 MPa, 3.2mm, unannealed 199 °C ASTM D 648
HDT, 0.45 MPa, 6.4 mm, unannealed 206 °C ASTM D 648
HDT, 1.82 MPa, 6.4 mm, unannealed 202 °C ASTM D 648
CTE, -40°C to 150°C, flow 3.2E-05 1/°C ASTM E 831
CTE, -40°C to 150°C, xflow 3.5E-05 1/°C ASTM E 831
Thermal Conductivity 0.32 W/m-°C ISO 8302
CTE, 23°C to 150°C, flow 3.2E-05 1/°C ISO 11359-2
CTE, 23°C to 150°C, xflow 3.5E-05 1/°C ISO 11359-2
Ball Pressure Test, 125°C +/- 2°C Passes - IEC 60695-10-2
Vicat Softening Temp, Rate B/50 211 °C ISO 306
Vicat Softening Temp, Rate B/120 213 °C ISO 306
HDT/Bf, 0.45 MPa Flatw 80*10*4 sp=64mm 204 °C ISO 75/Bf
HDT/Af, 1.8 MPa Flatw 80*10*4 sp=64mm 192 °C ISO 75/Af

PHYSICAL

Specific Gravity 1.48 - ASTM D 792
Mold Shrinkage on Tensile Bar, flow (2) 0.4 - 0.6 % GE Method
Mold Shrinkage, flow, 3.2 mm 0.4 - 0.6 % GE Method
Mold Shrinkage, xflow, 3.2 mm 0.4 - 0.6 % GE Method
Melt Flow Rate, 337°C/6.6 kgf 13.7 g/10 min ASTM D 1238
Density 1.48 g/cm³ ISO 1183
Water Absorption, (23°C/sat) 0.9 % ISO 62
Moisture Absorption (23°C / 50% RH) 0.5 % ISO 62
Melt Volume Rate, MVR at 360°C/5.0 kg 14 cm³/10 min ISO 1133

ELECTRICAL

Arc Resistance, Tungsten {PLC} 5 PLC Code ASTM D 495
Hot Wire Ignition {PLC) 4 PLC Code UL 746A
High Voltage Arc Track Rate {PLC} 4 PLC Code UL 746A
High Ampere Arc Ign, surface {PLC} 4 PLC Code UL 746A
Comparative Tracking Index (UL) {PLC} 4 PLC Code UL 746A

FLAME CHARACTERISTICS

UL Recognized, 94V-0 Flame Class Rating (3) 0.4 mm UL 94

Source, GMD, Last Update:03/30/2004

1) Typical values only. Variations within normal tolerances are possible for variose colours.All values are measured at least after 48 hours storage at 230C/50% relative humidity.
All properties, expect the melt volume rate are measured on injection moulded samples.
All samples are prepared according to ISO 294.
2) Only typical data for material selection purpose.Not to be used for part or tool design.
3) This rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.
4) Own measurement according to UL.

Ultem* Resin 2312EPR
Europe-Africa-Middle East: COMMERCIAL

PROCESSING PARAMETERS TYPICAL VALUE UNIT

Injection Molding

Drying Temperature 150 °C
Drying Time 4 - 6 hrs
Drying Time (Cumulative) 24 hrs
Maximum Moisture Content 0.02 %
Melt Temperature 350 - 400 °C
Nozzle Temperature 345 - 400 °C
Front - Zone 3 Temperature 345 - 400 °C
Middle - Zone 2 Temperature 340 - 400 °C
Rear - Zone 1 Temperature 330 - 400 °C
Mold Temperature 135 - 165 °C
Back Pressure 0.3 - 0.7 MPa
Screw Speed 40 - 70 rpm
Shot to Cylinder Size 40 - 60 %
Vent Depth 0.025 - 0.076 mm

Source, GMD, Last Update:03/30/2004

1) Typical values only. Variations within normal tolerances are possible for variose colours.All values are measured at least after 48 hours storage at 230C/50% relative humidity.
All properties, expect the melt volume rate are measured on injection moulded samples.
All samples are prepared according to ISO 294.
2) Only typical data for material selection purpose.Not to be used for part or tool design.
3) This rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.
4) Own measurement according to UL.

21 Tensile strength experiment

21.1 Test data:

Samples with:

PS 158 K
PS 158 K with app. 30% glass fiber

Data for test samples:
$Length: 107\,mm$

$Area \quad : 4\,mm \cdot 10\,mm = 40\,mm^2$

Strain rate: 5 mm / min
Room temperature: 21 degree

Short glass fiber
Fiber length : 0,5mm-1mm
Diameter : 5µm-10µm

Calculating young's modulus:

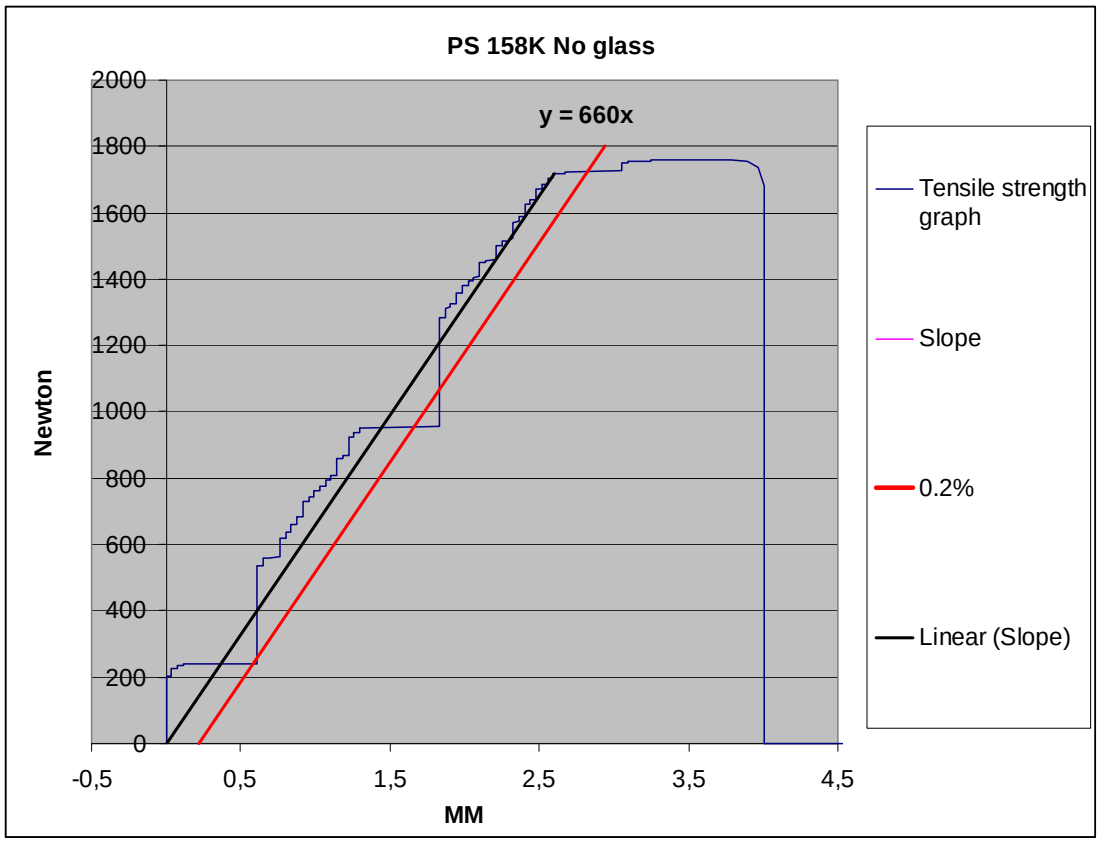
$$Stress: \quad \sigma = \frac{F}{A}$$

$$Strain: \quad \varepsilon_n = \frac{\Delta L}{L}$$

$$Young`s\,Modulus \quad E = \frac{\sigma}{\varepsilon_n} \Rightarrow \quad \frac{\frac{F}{A}}{\frac{\Delta L}{L}}$$

21.2 Calculations

Sample 1



$$\sigma = \frac{1721\,N}{40\cdot 10^{-6}\,m^2} = 43.025\cdot 10^{6}\,Pa$$

Delta L comes from the graph.

$$\varepsilon_n = \frac{2.82\cdot 10^{-3}\,m}{107\cdot 10^{-3}\,m} = 26.355\cdot 10^{-3}$$

$$E = \frac{43.025\cdot 10^{6}\,Pa}{26.355\cdot 10^{-3}} = 1.63251\cdot 10^{9}\,Pa \approx \underline{\underline{1.63\,GPa}}$$

> *Young`s Modulus PS1*

>

> *restart*;

> "PS 158 K No glass";

K 1;

$9.6258\,x^4$ K $143.27\,x^3$ C $447.96\,x^2$ C $200.64\,x$ C 208.38;

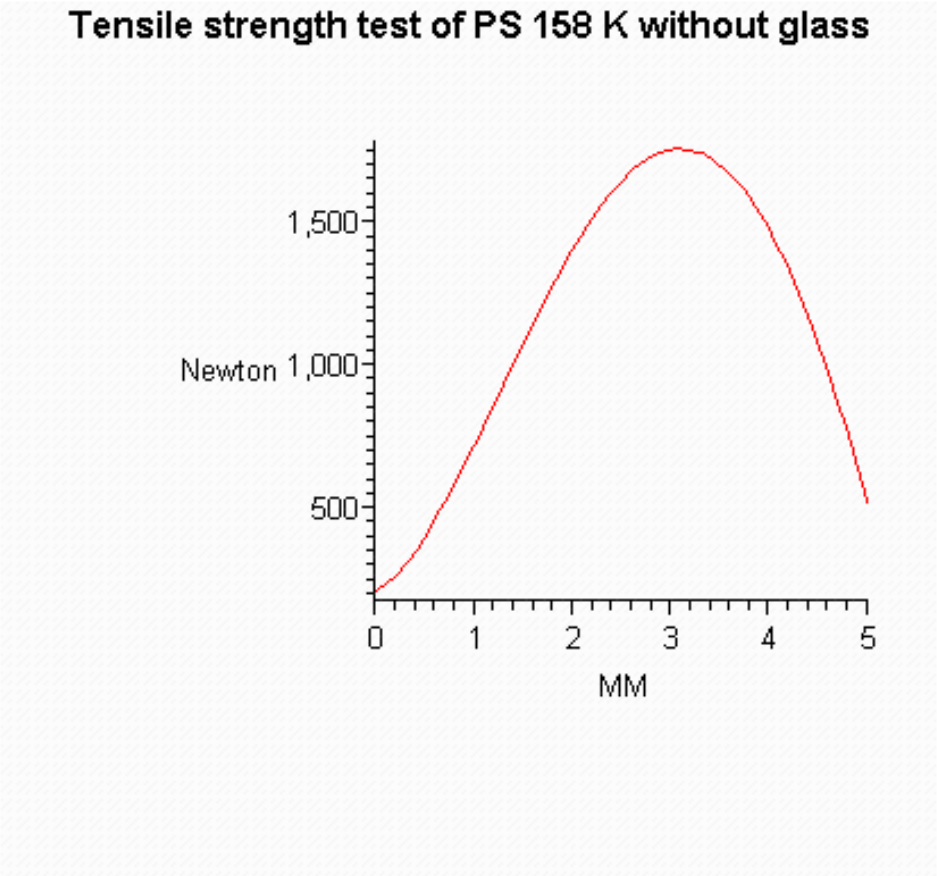
1

$$9.6258\,x^4 \text{ K } 143.27\,x^3 \text{ C } 447.96\,x^2 \text{ C } 200.64\,x \text{ C } 208.38$$

> $\frac{d}{dx}\left(9.6258\,x^4 - 143.27\,x^3 + 447.96\,x^2 + 200.64\,x + 208.38\right)$

$$38.5032\,x^3 - 429.81\,x^2 + 895.92\,x + 200.64$$

```
> plot(9.6258*x^4-143.27*x^3+447.96*x^2+200.64*x
  +208.38, x=0..5, labels=["MM","Newton"],
  title="Tensile strength test of PS 158 K without glass"
  titlefont=[HELVETICA, BOLD, 12]);
```




```
> solve(38.5032*x^3-429.81*x^2+895.92*x+200.64=0,x);
```

$$3.091746015,\ 8.274904833,\ -.2036825749$$

```
> x1:=3.091746015;
```

$$x1 := 3.091746015$$

```
> 9.6258*3.091746015^4-
143.27*3.091746015^3+447.96*3.091746015^2+200.64*3.091746015+208.38;
```

> $F := 1756.088290;$
$1;$
$\mathrm{DL} := 0.003091746015;$
$1;$
$L := 0.107;$
$1;$
$A := 0.000040;$
1

$$1$$
$$756.088290$$

$$0$$
$$.003091746015$$

$$0$$
$$.107$$

$$0$$
$$.000040$$

> $\mathrm{s} := \frac{F}{A};\ 1;\ 3 := \frac{\mathrm{DL}}{L};\ 1;\ Emodul := \frac{\mathrm{s}}{3};\ 1$

$$\mathrm{s} := 4.390220725\ 10^{7}$$

$$3 := 0.02889482257$$

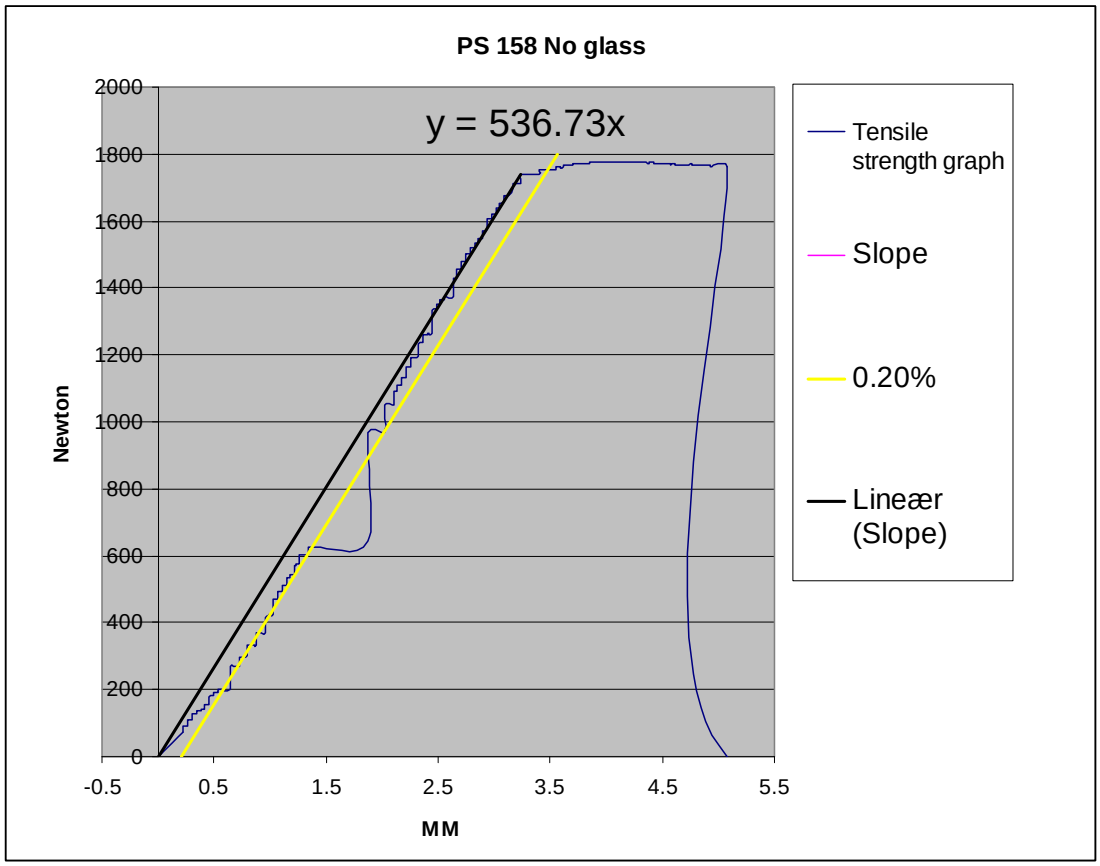
$$Emodul := 1.519379714\ 10^{9}$$

>

>

Young`s modulus is app. 1.52 GPa'

Sample 2:



$$\sigma = \frac{1739\,N}{40\cdot 10^{-6}\,m^2} = 43.475\cdot 10^{6}\,Pa$$

Delta L comes from the graph:

$$\varepsilon_n = \frac{3.4\cdot 10^{-3}\,m}{107\cdot 10^{-3}\,m} = 31.7757\cdot 10^{-3}$$

$$E = \frac{43.475\cdot 10^{6}\,Pa}{31.7757\cdot 10^{-3}} = 1.36818\cdot 10^{9}\,Pa \approx \underline{1.37\,GPa}$$

Young`s Modulus PS2

```
> restart; 1; with(linalg); 1
```

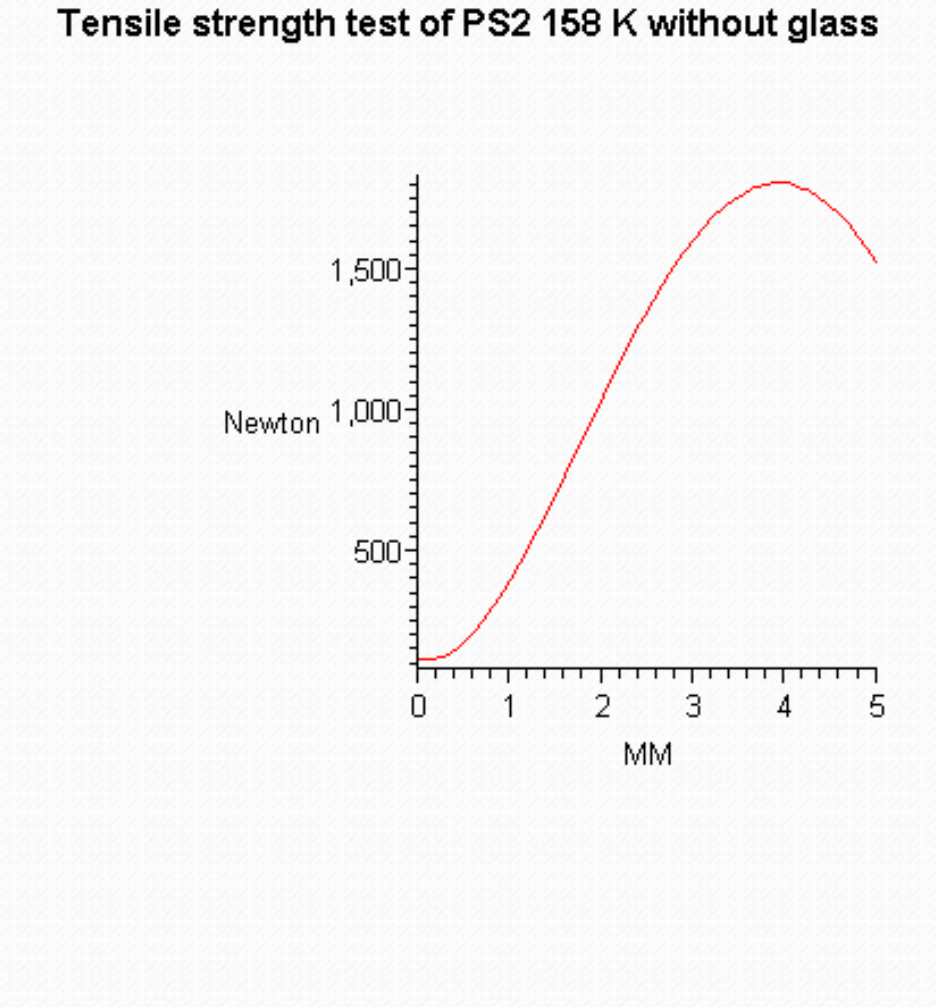
```
> "PS2 158K NO GLAS": 6.7543$x^4 K 114.69$x^3
    C 479.52$x^2 K 93.399$x C 118.57;
```

$$6.7543\,x^4 - 114.69\,x^3 + 479.52\,x^2 - 93.399\,x + 118.57$$

```
> d/dx (6.7543 x^4 K 114.69 x^3
    C 479.52 x^2 K 93.399 x C 118.57)
```

$$27.0172\,x^3 - 344.07\,x^2 + 959.04\,x - 93.399$$

```
> plot(6.7543 x^4 K 114.69 x^3 C 479.52 x^2 K 93.399 x
    C 118.57, x = 0 ..5, labels = ["MM", "Newton"],
    title = "Tensile strength test of PS2 158 K without glass"
    titlefont = [HELVETICA, BOLD, 12]);
```



```
> solve(27.0172 x^3 K 344.07 x^2 C 959.04 x K 93.399 = 0, x); 1
```

0.1010201966, 3.932844087, 8.701356242

```
> x1 := 3.932844087; 1
```

3
.932844087

```
> 6.7543 ^(3.932844087, 4) K 114.69 ^(3.932844087, 3)
    C 479.52 ^(3.932844087, 2) K *(93.399, 3.932844087)
    C 118.57;
    1
```

1
807.350400

```
> F := 1807.350400;
    1;
    DeltaL := 0.003932844087;
    1;
    L := 0.107;
    1;
    A := 0.000040;
    1
```

1
807.350400

0
.003932844087

0
.107

0
.000040

```
>
```

> $s := \frac{F}{A};\ 1;\ 3 := \frac{DeltaL}{L};\ 1;\ Emodul := \frac{s}{3};\ 1$

$$4.518376000\ 10^{7}$$

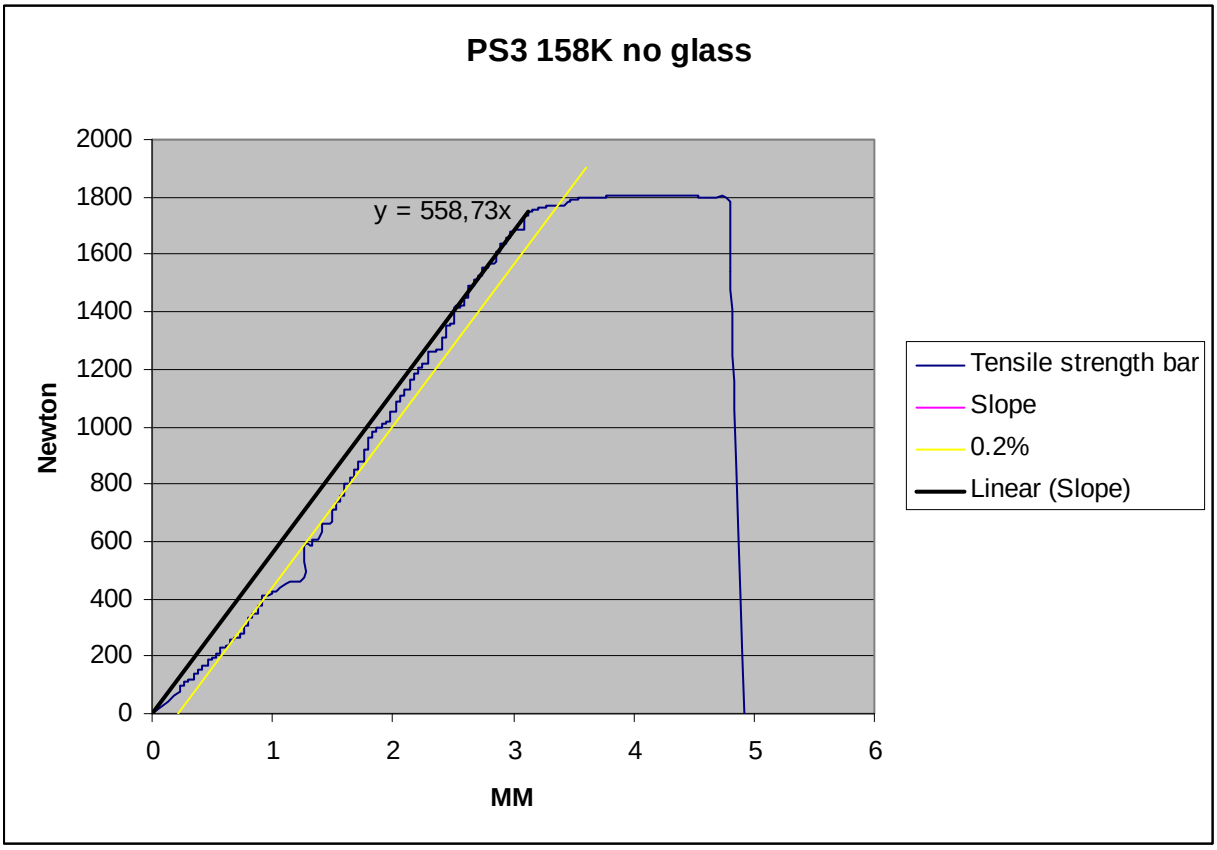
$$0$$
$$.03675555221$$

$$1.229304344\ 10^{9}$$

>

Young`s modulus is app. 1.2 GPa

Sample 3



$$\sigma = \frac{1810\,N}{40\cdot 10^{-6}\,m^2} = 45.25\cdot 10^{6}\,Pa$$

Delta L comes from the graph:

$$\varepsilon_n = \frac{3.68\cdot 10^{-3}\,m}{107\cdot 10^{-3}\,m} = 34.3925\cdot 10^{-3}$$

$$E = \frac{43.475\cdot 10^{6}\,Pa}{31.7757\cdot 10^{-3}} = 1.36818\cdot 10^{9}\,Pa \approx \underline{\underline{1.315\,GPa}}$$

Young`s Modulus PS3

```
> restart;
```

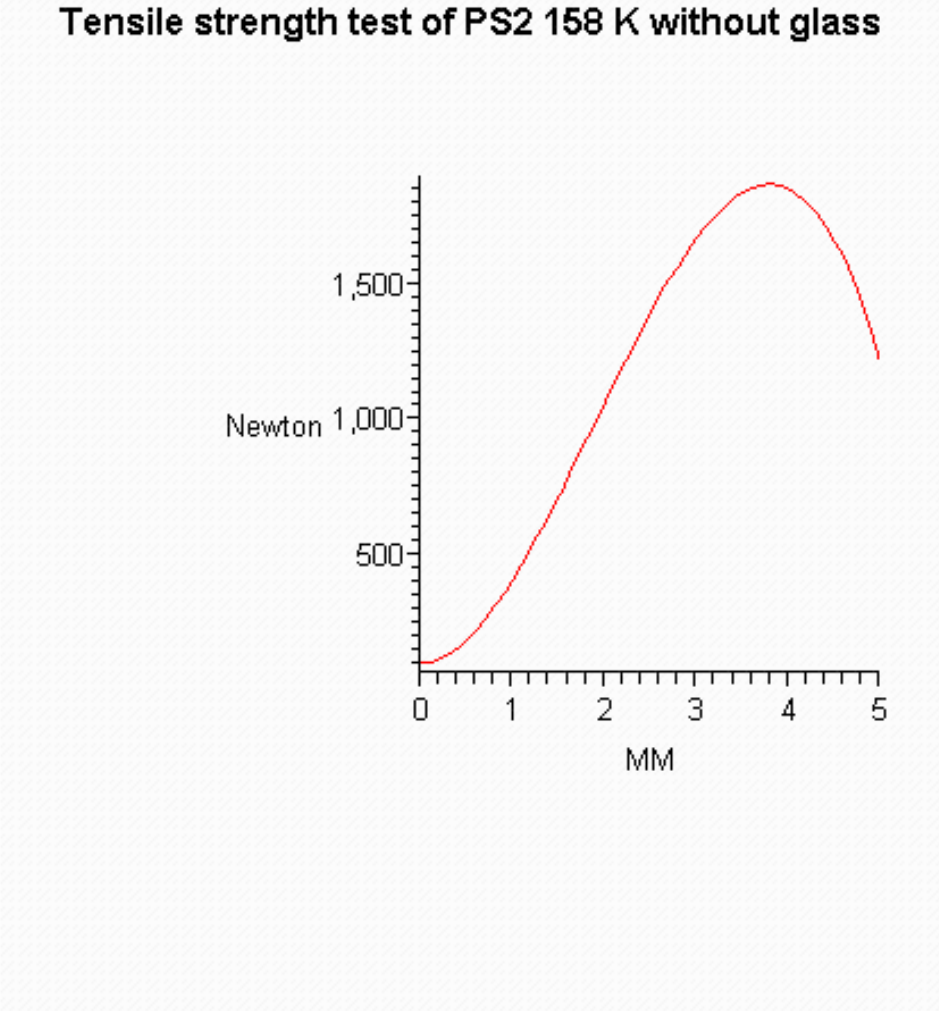
> 64.389x^3 C 366.23$x^2 C 3.0325$x
C 98.312;

$$\$64.389\,x^3 \mathrm{C}\ 366.23\,x^2 \mathrm{C}\ 3.0325\,x \mathrm{C}\ 98.312$$

> *diff*((1), *x*)

$$\$193.167\,x^2 \mathrm{C}\ 732.46\,x \mathrm{C}\ 3.0325$$

> *plot*($64.389 x^3 C 366.23 x^2 C 3.0325 *x* C 98.312, *x* = 0 ..5,
labels = ["MM", "Newton"],
title =" *Tensile strength test of PS2 158 K without glass*",
titlefont = [*HELVETICA*, *BOLD*, 12]);



> *solve*($193.167 x^2 C 732.46 *x* C 3.0325 = 0, *x*);

$$\$0.004135647207,\ 3.795984151$$

> $x1 := 3.795984151;$

$$x1 := 3.795984151$$

> $64.389 \cdot 3.795984151^3 + 366.23 \cdot 3.795984151^2 + 3.0325 \cdot 3.795984151 + 98.312;$

$$1$$
$$865.049414$$

> $F := 1865.049414;\ DeltaL := 0.0037959;\ L := 0.00107;\ A := 0.00000040;$

$$F := 1865.049414$$

$$DeltaL := 0.0037959$$

$$L := 0.00107$$

$$A := 4.0\ 10^{-7}$$

>

> $s := \frac{F}{A};\ e := \frac{DeltaL}{L};\ Emodul := \frac{s}{e};$

$$s := 4.662623535\ 10^{9}$$

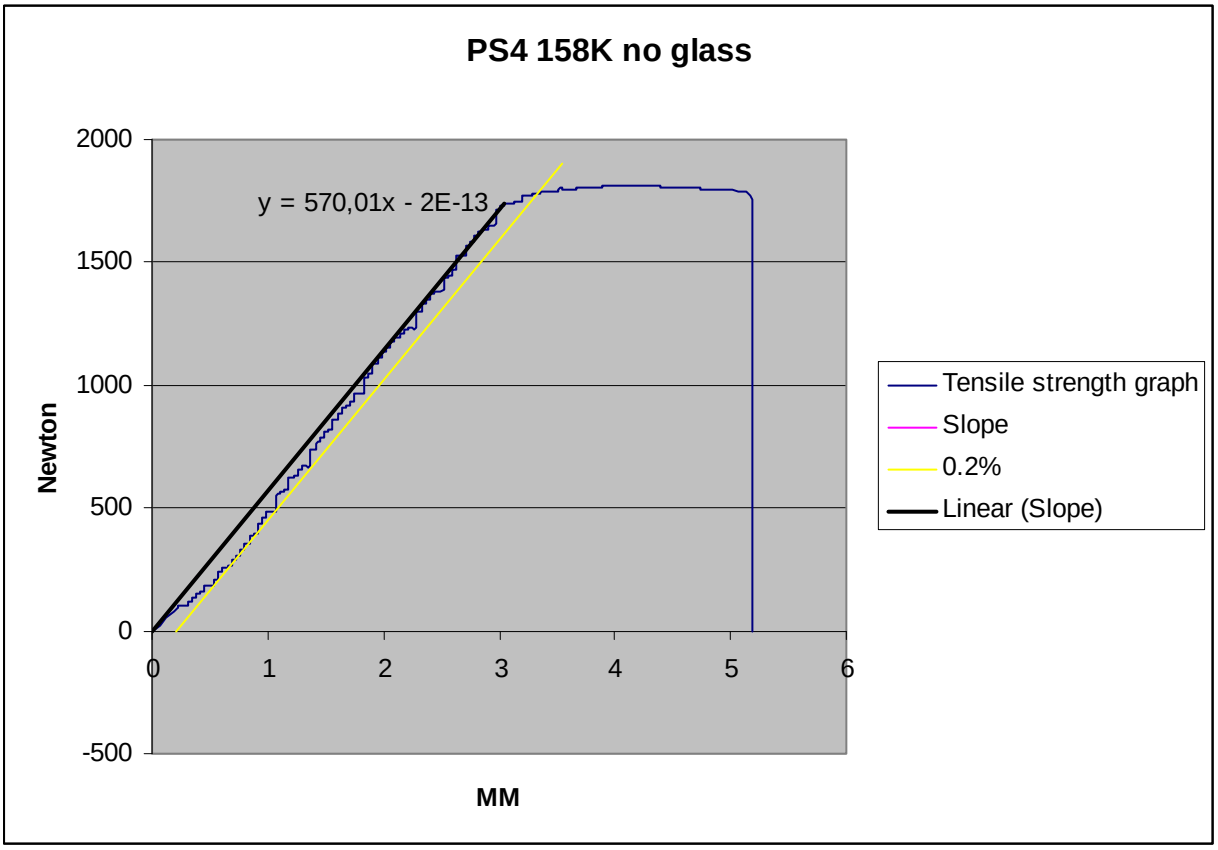
$$e := 3.547570093$$

$$Emodul := 1.314314704\ 10^{9}$$

>

Young`s modulus is app. 1.31 GPa

Sample 4



$$\sigma = \frac{1807\,N}{40\cdot 10^{-6}\,m^2} = 45.175\cdot 10^{6}\,Pa$$

Delta L comes from the graph:

$$\varepsilon_n = \frac{3.54\cdot 10^{-3}\,m}{107\cdot 10^{-3}\,m} = 33.08\cdot 10^{-3}$$

$$E = \frac{45.175\cdot 10^{6}\,Pa}{33.08\cdot 10^{-3}} = 1.35628\cdot 10^{9}\,Pa \approx \underline{\underline{1.35\,GPa}}$$

Young`s Modulus PS4

> *restart*;

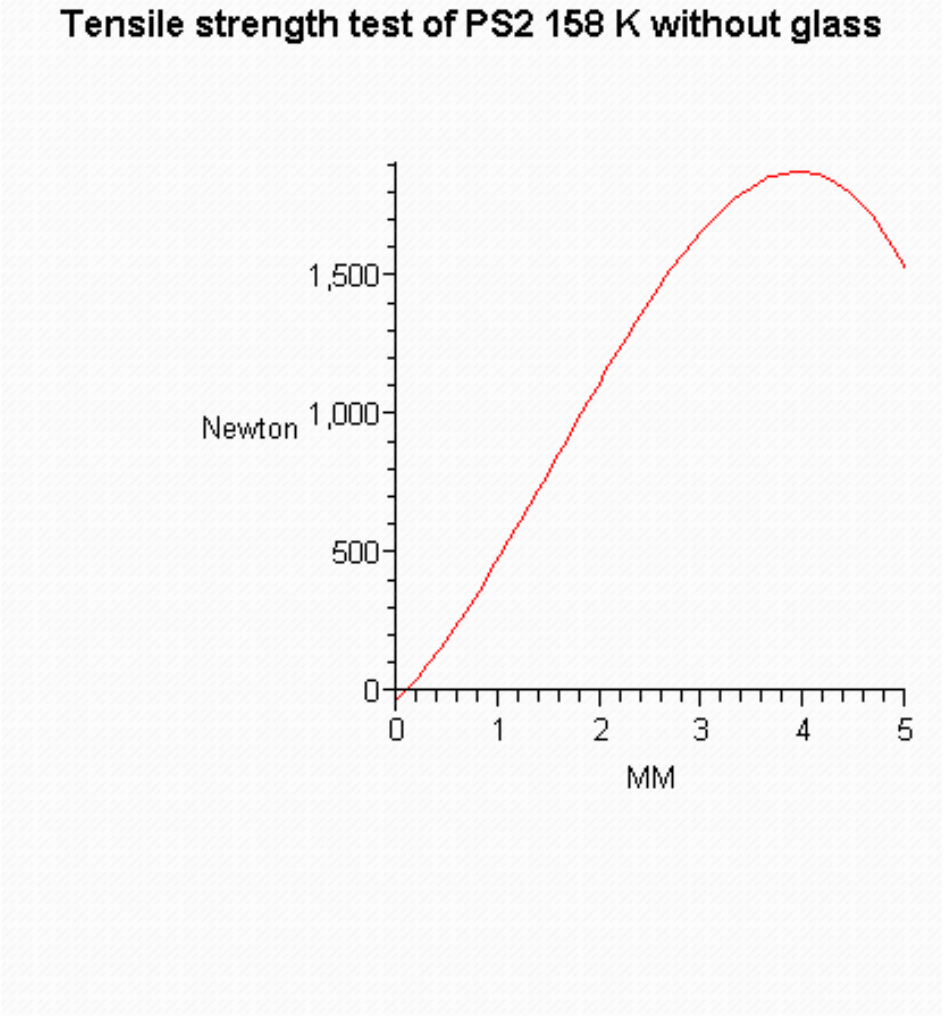
> 38.327x^3 C 180.85$x^2
C 365.64$x $ 28.439;

$$\$38.327\,x^3 \mathrm{C}\ 180.85\,x^2 \mathrm{C}\ 365.64\,x\ \$28.439$$

> *diff*((1), *x*)

$$\$114.981\,x^2 \mathrm{C}\ 361.70\,x \mathrm{C}\ 365.64$$

> *plot*(38.327x^3 C 180.85$x^2 C 365.64$x $ 28.439, *x* = 0 ..5,
labels = ["MM", "Newton"],
title =" *Tensile strength test of PS2 158 K without glass*",
titlefont = [*HELVETICA*, *BOLD*, 12]);



> *solve*($114.981 *x*^2 C 361.70 *x* C 365.64 = 0, *x*);

$$\$.8049285630,\ 3.950665685$$

> $x1 := 3.950665685;$

$$x1 := 3.950665685$$

> $38.327 \$3.950665685^3 + 180.85 \$3.950665685^2 + 365.64 \$3.950665685 \$28.439;$

$$1$$
$$875.463026$$

> $F := 1875.463026;\ DeltaL := 0.003950665685;\ L := 0.00107;\ A := 0.00000040;$

$$F := 1875.463026$$

$$DeltaL := 0.003950665685$$

$$L := 0.00107$$

$$A := 4.0\ 10^{-7}$$

>

> $s := \frac{F}{A};\ e := \frac{DeltaL}{L};\ Emodul := \frac{s}{e};$

$$s := 4.688657565\ 10^9$$

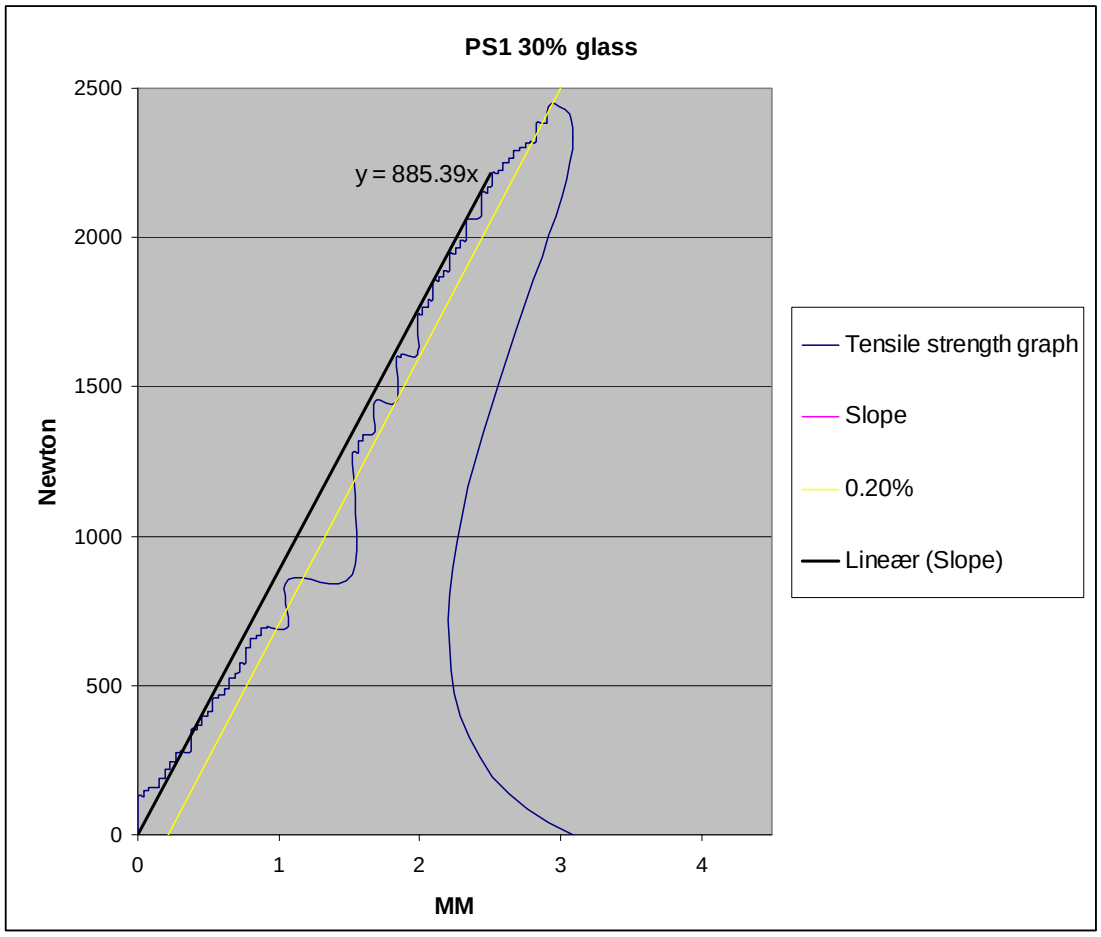
$$e := 3.692210921$$

$$Emodul := 1.269878039\ 10^9$$

>

Young`s modulus is app. 1.3 GPa

Sample PS1 30% glass



$$\sigma = \frac{2446.7\,N}{40\cdot 10^{-6}\,m^2} = 61.1675\cdot 10^{6}\,Pa$$

Delta L comes from the graph:

$$\varepsilon_n = \frac{2.937\cdot 10^{-3}\,m}{107\cdot 10^{-3}\,m} = 27.4486\cdot 10^{-3}$$

$$E = \frac{61.1675\cdot 10^{6}\,Pa}{27.4486\cdot 10^{-3}} = 2.22844\cdot 10^{9}\,Pa \approx \underline{2.2\,GPa}$$

Young`s Modulus PS1 30% glass

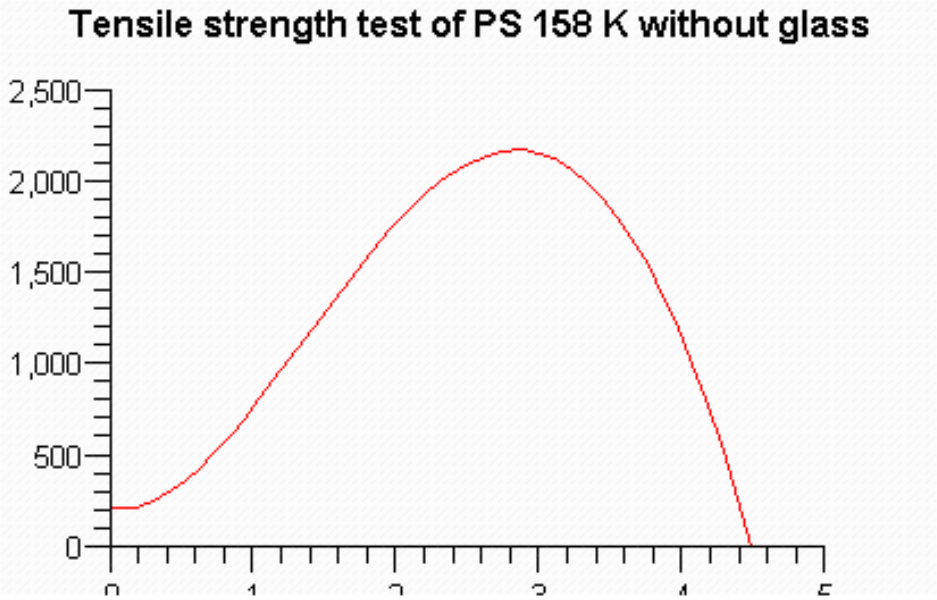
> 13.427 x^4 K 262.31 x^3 C 920.18 x^2 K 110.74 x C 208.3; 1

$$13.427\,x^4 - 262.31\,x^3 + 920.18\,x^2 - 110.74\,x + 208.3$$

```
> d/dx (13.427 x^4 - 262.31 x^3
    + 920.18 x^2 - 110.74 x + 208.3);
```

$$53.708\,x^3 - 786.93\,x^2 + 1840.36\,x - 110.74$$

```
>
> plot(13.427 x^4 - 262.31 x^3 + 920.18 x^2 - 110.74 x
    + 208.3, x = 0..5, y = 0..2500, labels = ["MM", "Newton"]
    , title = "Tensile strength test of PS 158 K without glass"
    , titlefont = [HELVETICA, BOLD, 12]);
```




```
> solve(53.708 x^3 - 786.93 x^2 + 1840.36 x - 110.74 = 0, x);
```

$$0.06179916838,\ 2.839301726,\ 11.75090626$$

```
> x1 := 2.839301726;
```

$$2.839301726$$

```
> 13.427 ^(2.839301726, 4) - 262.31 ^(2.839301726, 3)
    + 920.18 ^(2.839301726, 2) - *(110.74, 2.839301726)
    + 208.3;
```

$$2$$
$$180.528689$$

> $F := 2180.528689;$
$1;$
$DeltaL := 0.002839301726;$
$1;$
$L := 0.107;$
$1;$
$A := 0.000040;$
1

$$2$$
$$180.528689$$

$$0$$
$$.002839301726$$

$$0$$
$$.107$$

$$0$$
$$.000040$$

> $s := \frac{F}{A};\ 1;\ 3 := \frac{DeltaL}{L};\ 1;\ Emodul := \frac{s}{3};\ 1$

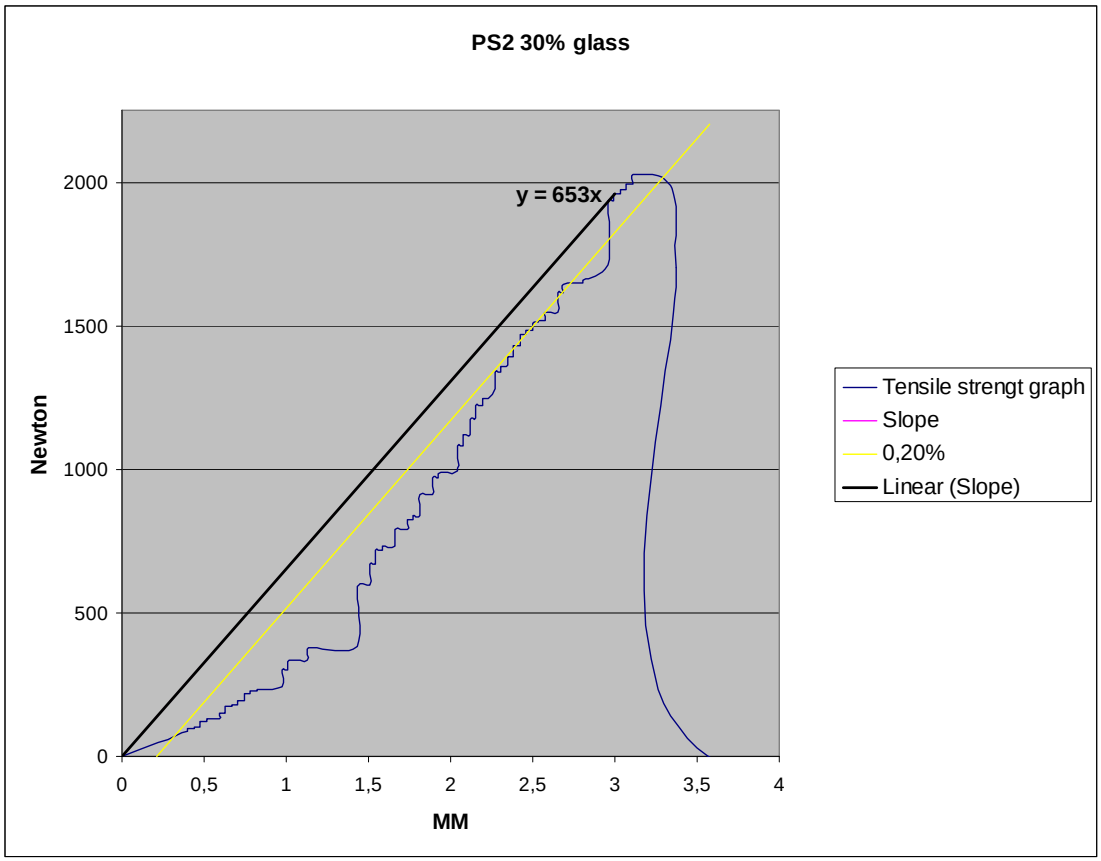
$$5.451321722\ 10^{7}$$

$$2.054348148\ 10^{9}$$

>

Young`s modulus is app. 2.0 GPa

Sample PS2 30% glass



$$\sigma = \frac{2023\,N}{40\cdot 10^{-6}\,m^2} = 50.57\cdot 10^{6}\,Pa$$

Delta L comes from the graph:

$$\varepsilon_n = \frac{3{,}26\cdot 10^{-3}\,m}{107\cdot 10^{-3}\,m} = 30.4673\cdot 10^{-3}$$

$$E = \frac{50.57\cdot 10^{6}\,Pa}{30.4673\cdot 10^{-3}} = 1.65998\cdot 10^{9}\,Pa \approx \underline{\underline{1.6\,GPa}}$$

Young`s Modulus PS2 30% glass

```
> restart;
```

```
> 5.4904 x^4 K  97.55 x^3 C  421.19 x^2 C  60.293 x K  42.903;
```

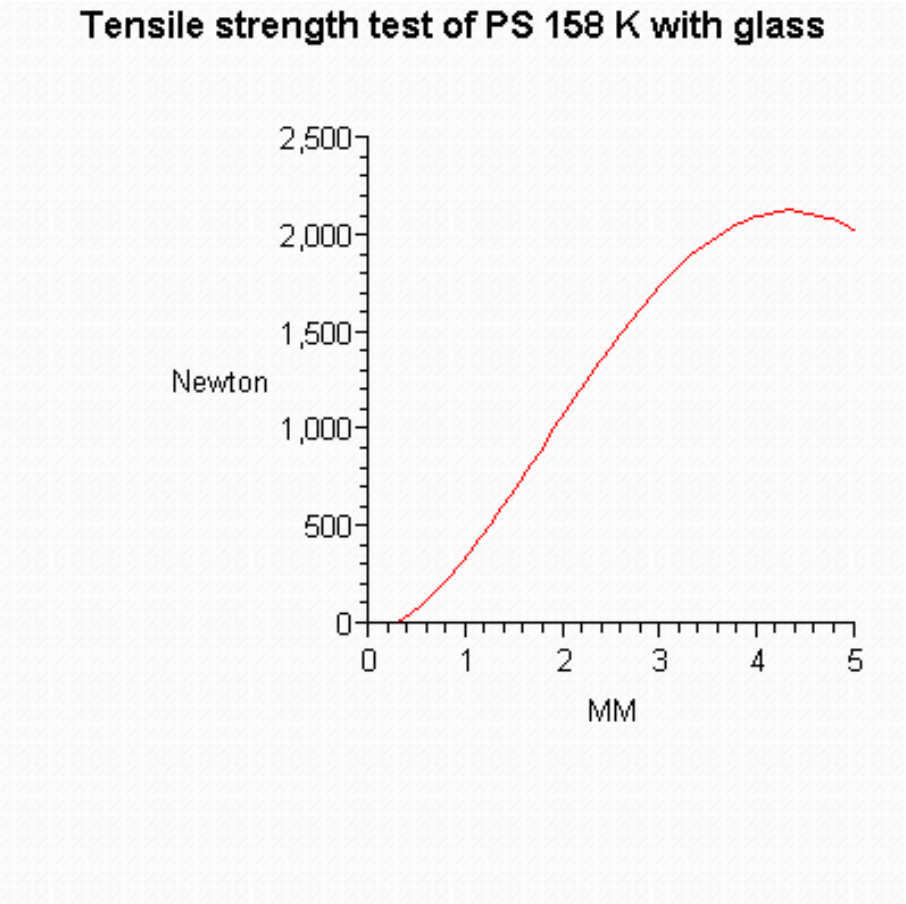
$$5.4904\,x^4\,K\;\;97.55\,x^3\,C\;\;421.19\,x^2\,C\;\;60.293\,x\,K\;\;42.903$$

> $\frac{d}{dx}\left(5.4904\,x^4 - 97.55\,x^3 + 421.19\,x^2 + 60.293\,x - 42.903\right)$

$$21.9616\,x^3 - 292.65\,x^2 + 842.38\,x + 60.293$$

>

> $plot(5.4904\,x^4 - 97.55\,x^3 + 421.19\,x^2 + 60.293\,x - 42.903,\ x = 0..5,\ y = 0..2500,\ labels = ["MM", "Newton"],\ title = "Tensile\ strength\ test\ of\ PS\ 158\ K\ with\ glass",\ titlefont = [HELVETICA, BOLD, 12])$;



> $solve(21.9616\,x^3 - 292.65\,x^2 + 842.38\,x + 60.293 = 0, x)$;

$$4.338397401,\ 9.057004159,\ -0.06986972244$$

> $x1 := 4.338397401$;

$$x1 := 4.338397401$$

>

$$5.4904\ \$4.338397401^4\ \mathrm{K}\ \ 97.55\$4.338397401^3\ \mathrm{C}\ \ 421.19\ \$4.338397401^2\ \mathrm{C}\ \ 60.293\$4.338397401\ \mathrm{K}\ \ 42.903;$$

$$2$$

$$125.647270$$

> $F := 2125.647270$;

$DeltaL := 4.338397401\mathrm{EK}\ 3$;

$L := 0.107$;

$A := 0.000040$;

$$F := 2125.647270$$

$$DeltaL := 0.004338397401$$

$$L := 0.107$$

$$A := 0.000040$$

> $\mathrm{s} := \frac{F}{A}$; $3 := \frac{DeltaL}{L}$; $Emodul := \frac{\mathrm{s}}{3}$;

$$\mathrm{s} := 5.314118175\ 10^7$$

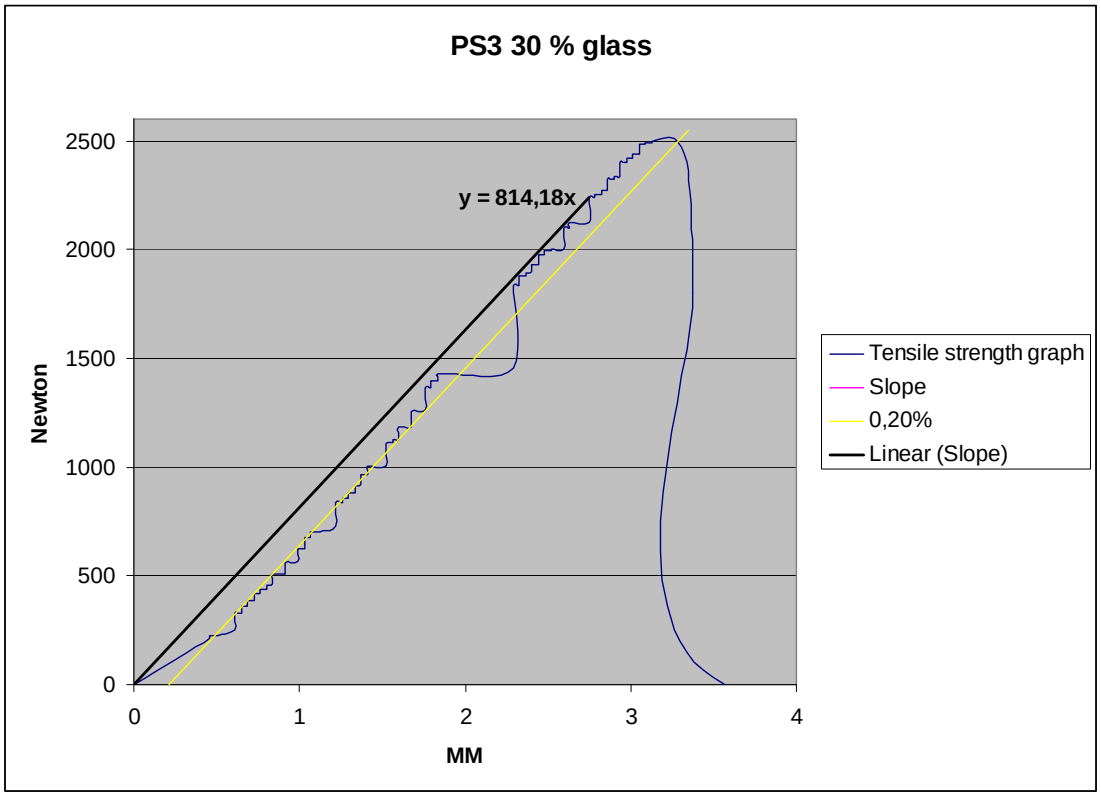
$$3 := 0.04054577010$$

$$Emodul := 1.310646749\ 10^9$$

>

Young`s modulus is app. 1.3GPa

Sample PS3 30% glass



$$\sigma = \frac{2510\,N}{40\cdot 10^{-6}\,m^2} = 62.75\cdot 10^{6}\,Pa$$

Delta L comes from the graph:

$$\varepsilon_n = \frac{3{,}26\cdot 10^{-3}\,m}{107\cdot 10^{-3}\,m} = 30.4673\cdot 10^{-3}$$

$$E = \frac{62.75\cdot 10^{6}\,Pa}{30.4673\cdot 10^{-3}} = 2.05959\cdot 10^{9}\,Pa \approx \underline{\underline{2.1GPa}}$$

Young`s Modulus PS3 30% glass

```
> restart;
> 4.6394$x^4 - 73.837$x^3 C 202.08$x^2 C 751.91$x
  - 234.46;
```

$$4.6394\,x^4 \mathrm{K}\ 73.837\,x^3 \mathrm{C}\ 202.08\,x^2 \mathrm{C}\ 751.91\,x \mathrm{K}\ 234.46$$

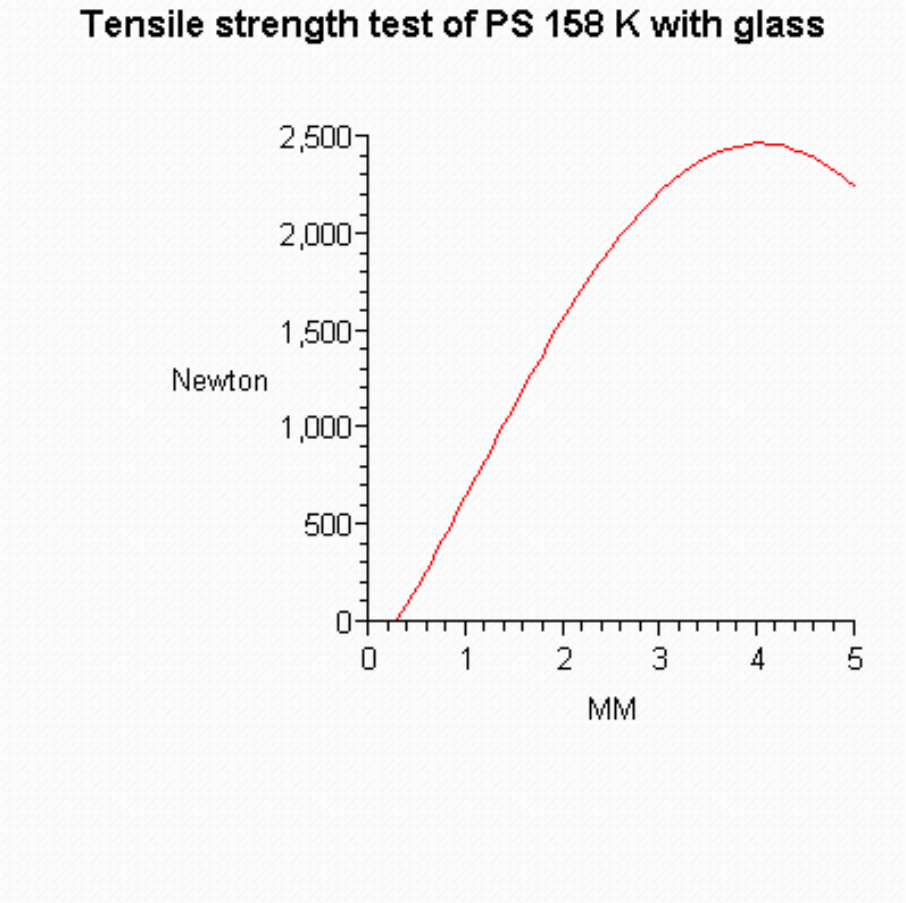
```
> diff ( (1), x )
```

$$18.5576\,x^3 - 221.511\,x^2 + 404.16\,x + 751.91$$

>

>

> *plot*(4.6394$x^4 - 73.837$x^3 + 202.08$x^2 + 751.91$x - 234.46, *x* = *0* ..*5*, *y* = *0* ..*2500*, *labels* = ["MM", "Newton"], *title* =" *Tensile strength test of PS* 158 *K with glass*", *titlefont* = [*HELVETICA*, *BOLD*, 12]);



> *solve*(18.5576 x^3 − 221.511 x^2 + 404.16 *x* + 751.91 = 0, *x*);

$$4.025277418,\ 9.026290478,\ -1.115164482$$

> *x1* := 4.025277418 ;

$$x1 := 4.025277418$$

> $4.6394 \cdot 4.025277418^4 - 73.837 \cdot 4.025277418^3 + 202.08 \cdot 4.025277418^2 + 751.91 \cdot 4.025277418 - 234.46$

$$2$$
$$468.730821$$

> $F := 2468.730821$
;
$DeltaL := 0.004025277418;$
;
$L := 0.107;$
;
$A := 0.000040;$

$$F := 2468.730821$$

$$DeltaL := 0.004025277418$$

$$L := 0.107$$

$$A := 0.000040$$

> $\mathsf{s} := \frac{F}{A}$; $\mathsf{3} := \frac{DeltaL}{L}$; $Emodul := \frac{\mathsf{s}}{\mathsf{3}}$;

$$\mathsf{s} := 6.171827052\ 10^{7}$$

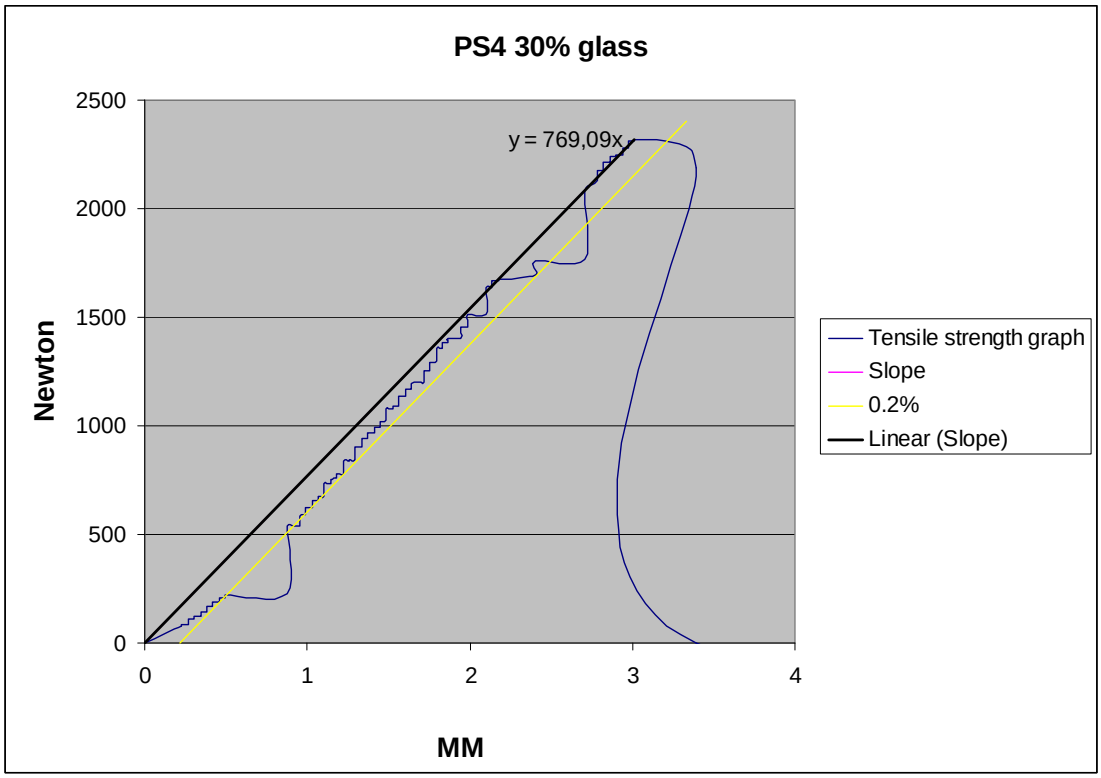
$$\mathsf{3} := 0.03761941512$$

$$Emodul := 1.640596227\ 10^{9}$$

>

Young`s modulus is app. 1.6GPa

Sample PS4 30% glass



$$\sigma = \frac{2311{,}9\ N}{40 \cdot 10^{-6}\ m^2} = 57.797 \cdot 10^{6}\ Pa$$

Delta L comes from the graph:

$$\varepsilon_n = \frac{3{,}204 \cdot 10^{-3}\ m}{107 \cdot 10^{-3}\ m} = 29.9439 \cdot 10^{-3}$$

$$E = \frac{57.797 \cdot 10^{6}\ Pa}{29.94390 \cdot 10^{-3}} = 1.93018 \cdot 10^{9}\ Pa \approx \underline{\underline{1.9\,GPa}}$$

Young`s Modulus PS4 30% glass

```
> restart;
> w := 23.221 $x^4 - 350.45 $x^3 C 1236.1 $x^2 - 555.44 $x
     C 188.74;
```

$$w := 23.221\,x^4 - 350.45\,x^3 + 1236.1\,x^2 - 555.44\,x + 188.74$$

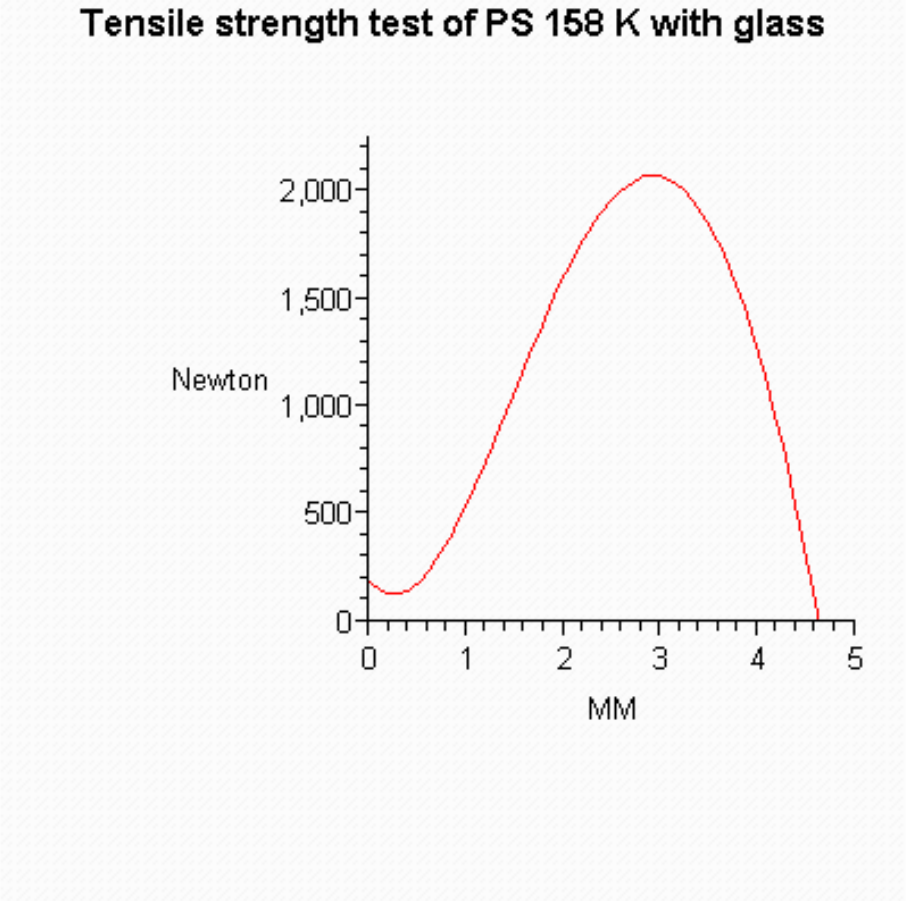
```
>
> k:= diff ( (1), x )
```

$$k := 92.884\,x^3 \mathrm{K}\ 1051.35\,x^2 \mathrm{C}\ 2472.2\,x \mathrm{K}\ 555.44$$

>

>

> *plot*(*w*, *x* = 0 ..5, *y* = 0 ..2250,
labels = ["MM", "Newton"], *title* =" *Tensile strength test of PS* 158 *K with glass*", *titlefont* = [*HELVETICA*, *BOLD*, 12]);



> *solve*(*k* = 0, *x*);

0.2508395133, 2.929037982, 8.139079483

> *x1* := 2.929037982 ;

$$x1 := 2.929037982$$

> $23.221\,\$2.929037982^4 - 350.45\,\$2.929037982^3$
C $1236.1\,\$2.929037982^2 - 555.44\,\$2.929037982$
C 188.74;

$$2$$
$$069.361643$$

> $F := 2069.361643$
;
$DeltaL := 2.929037982EK\ 3;$
;
$L := 0.107;$
;
$A := 0.000040;$

$$F := 2069.361643$$

$$DeltaL := 0.002929037982$$

$$L := 0.107$$

$$A := 0.000040$$

> $s := \frac{F}{A}\ ;\ 3 := \frac{DeltaL}{L};\quad Emodul := \frac{s}{3};$

$$s := 5.173404108\ 10^{7}$$

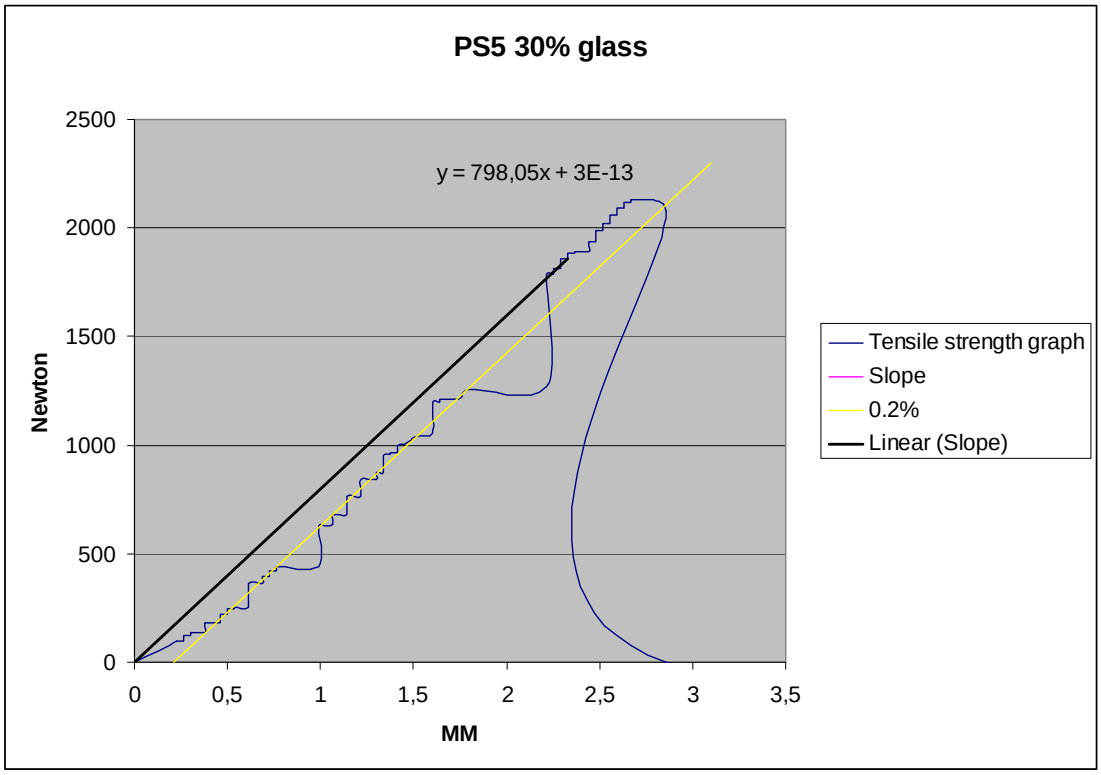
$$3 := 0.02737418675$$

$$Emodul := 1.889884129\ 10^{9}$$

>

Young`s modulus is app. 1.9GPa

Sample PS5 30% glass



$$\sigma = \frac{2079.77\,N}{40\cdot 10^{-6}\,m^2} = 51.99\cdot 10^{6}\,Pa$$

Delta L comes from the graph:

$$\varepsilon_n = \frac{2.861\cdot 10^{-3}\,m}{107\cdot 10^{-3}\,m} = 26.7383\cdot 10^{-3}$$

$$E = \frac{51.99\cdot 10^{6}\,Pa}{26.7383\cdot 10^{-3}} = 1.94456\cdot 10^{9}\,Pa \approx \underline{\underline{1.9\,GPa}}$$

Young`s Modulus PS5 30% glass

> *restart*;

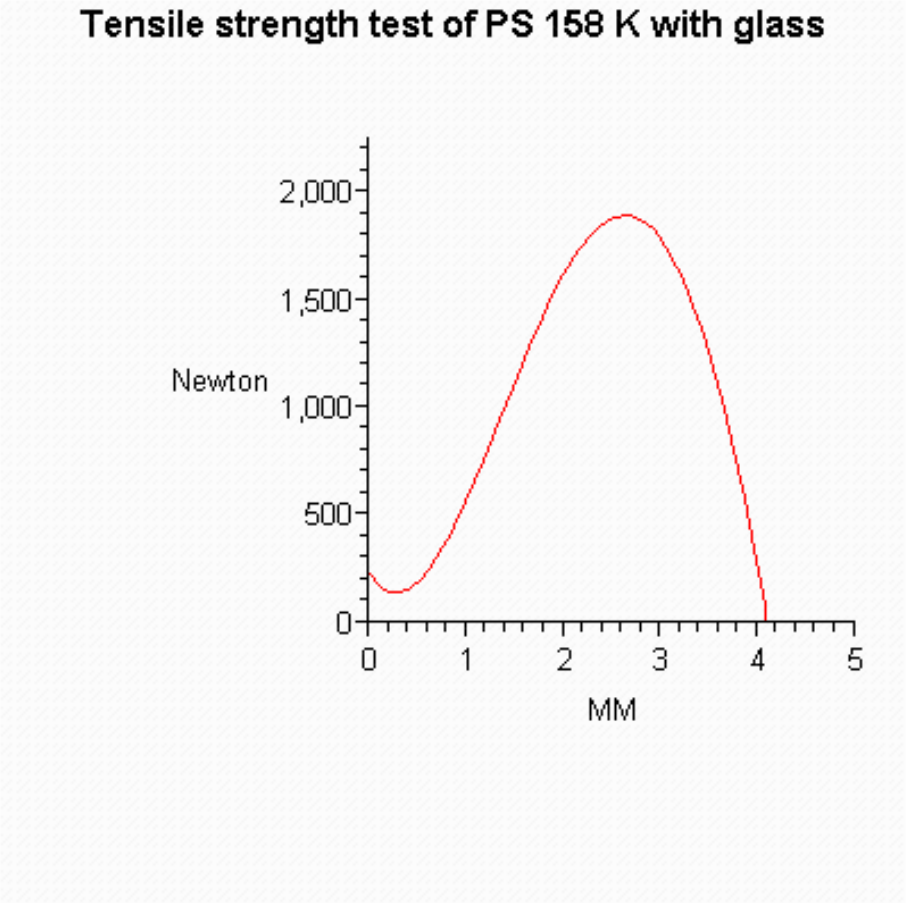
> $w := 30.258\$x^4 - 442.11\$x^3 \; C \; 1464.2\$x^2 - 711.93\$x \; C \; 228.28$

$$w := 30.258\,x^4 \; K \; 442.11\,x^3 \; C \; 1464.2\,x^2 \; K \; 711.93\,x \; C \; 228.28$$

```
>
> k:= diff ( (1), x )
```

$$k := 121.032\,x^3 \text{ K } 1326.33\,x^2 \text{ C } 2928.4\,x \text{ K } 711.93$$

```
>
>
> plot( w, x = 0 ..5, y = 0 ..2250,
  labels = [ "MM", "Newton"], title =" Tensile strength test of
  PS 158 K with glass", titlefont = [HELVETICA, BOLD, 12] );
```




```
> solve( k = 0, x );
```

$$0.2769814398,\ 2.641304169,\ 8.040221232$$

```
> x1 := 2.641304169 ;
```

$$x1 := 2.641304169$$

```
> 30.258$2.641304169^4 - 442.11$2.641304169^3
    C 1464.2$2.641304169^2 - 711.93$2.641304169
    C 228.28;
```

$$1$$
$$888.755774$$

> $F := 1888.755774$
;
$DeltaL := 0.002641304169;$
;
$L := 0.107;$
;
$A := 0.000040;$

$$F := 1888.755774$$

$$DeltaL := 0.002641304169$$

$$L := 0.107$$

$$A := 0.000040$$

> $\mathsf{s} := \frac{F}{A}$; $\mathsf{3} := \frac{DeltaL}{L}$; $Emodul := \frac{\mathsf{s}}{\mathsf{3}}$;

$$\mathsf{s} := 4.721889435\ 10^{7}$$

$$\mathsf{3} := 0.02468508569$$

$$Emodul := 1.912851142\ 10^{9}$$

>

Young`s modulus is app. 1.9GPa

22 Surface roughness

Roughness measurements

22.1 Sample no. 1

Material:	PEI
Injection Temp	380
Injection Speed	
Injection Pressure	60x15 bar

Data

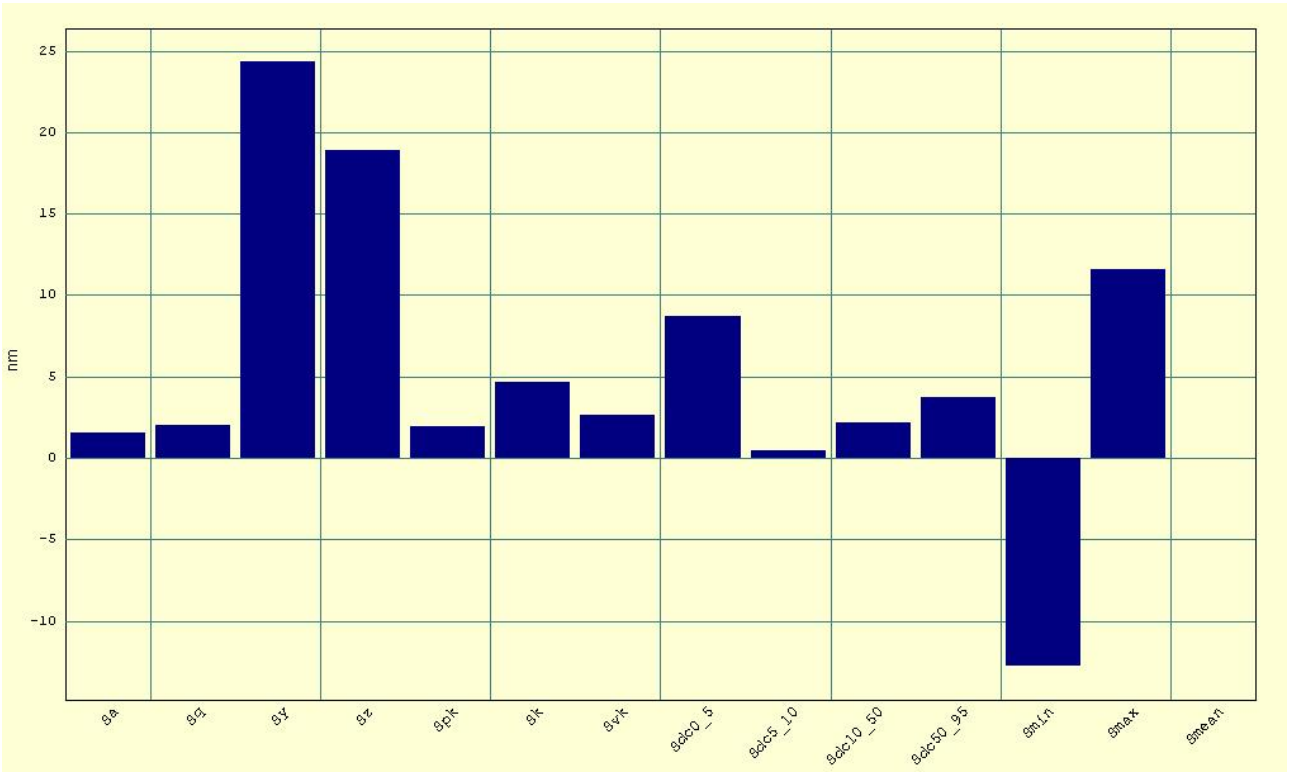
Roughness Data Calculated by SPIP V3.3.9.0
For file: C:\Documents and Settings\Administrator\Desktop\PIG60-1.IGM
20070612 13_26

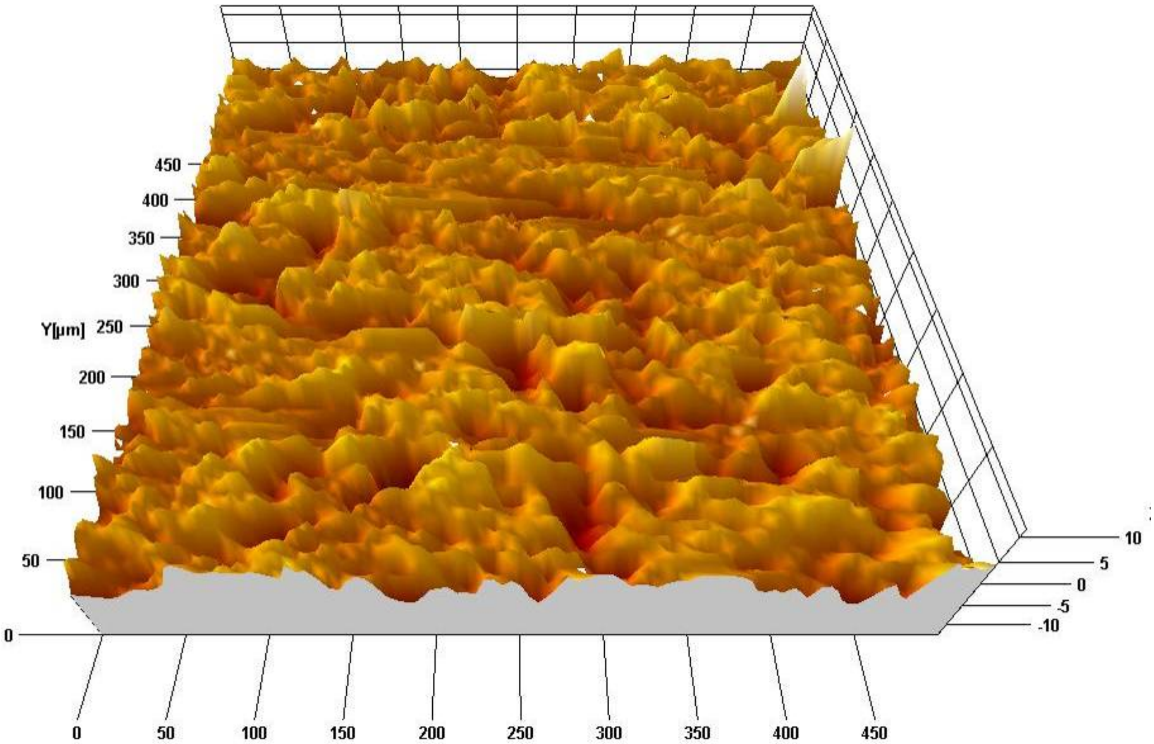
1-Xrange	2 Sa	3 Sq	4 Ssk	5 Sku	6 Sy	7 Sz	8 Sds	9 Ssc	10 Smin	11 Smax	12 Smean	13 Sti	14 Sdq	15 Sdr	16 S2A	17 S3A	18 Sbi	19 Sci	20 Svi	21 Spk	22 Sk	23 Svk	24 Std	25 Stdi	26 Srw	27 Srwi	28 Shw	29 Sfd	30 Scl20	31 Str20	32 Scl37	33 Str37	34 Sdc0_5	35 Sdc5_10	36 Sdc10_50	37 Sdc50_95
nm	µm	µm		µm	µm	1/um²	1/µm	µm	µm	µm	1/µm	%	µm²	µm²			µm	µm	µm	deg	µm	µm	µm	µm	µm	µm	µm	µm	µm	µm	µm	µm	µm	µm
504950		1.57	2.03	-0.616	4.84	24.4	18.9	0.00238	0.0075	-12.8	11.6	-0.00333	0.334	445	9.20	2.55E+5	2.78E+5	0.712	1.33	0.144	1.97	4.66	2.68	76.3	0.789	99.7	0.523	29.7	2.39	10.00	0.5	5.00	0.25	8.74	0.488	2.20	3.71

#C:\Documents and Settings\Administrator\Desktop\PIG60-1.IGM

Sa	**1.57**	**µm**
Sq	2.03	µm
Ssk	-0.616	
Sku	4.84	
Sy	24.4	µm
Sz	18.9	µm
Sds	0.00238	1/um²
Ssc	0.0075	1/µm
Smin	-12.8	µm
Smax	11.6	µm
Smean	-0.00333	µm
Sti	0.334	
Sdq	445	1/µm
Sdr	9.20	%
S2A	2.55E+5	µm²
S3A	2.78E+5	µm²
Sbi	0.712	

Sci	1.33	
Svi	0.144	
Spk	1.97	µm
Sk	4.66	µm
Svk	2.68	µm
Std	76.3	deg
Stdi	0.789	
Srw	99.7	µm
Srwi	0.523	
Shw	29.7	µm
Sfd	2.39	
Scl20	10.00	µm
Str20	0.5	
Scl37	5.00	µm
Str37	0.25	
Sdc0_5	8.74	µm
Sdc5_10	0.488	µm
Sdc10_50	2.20	µm
Sdc50_95	3.71	µm





22.2 Sample no. 2

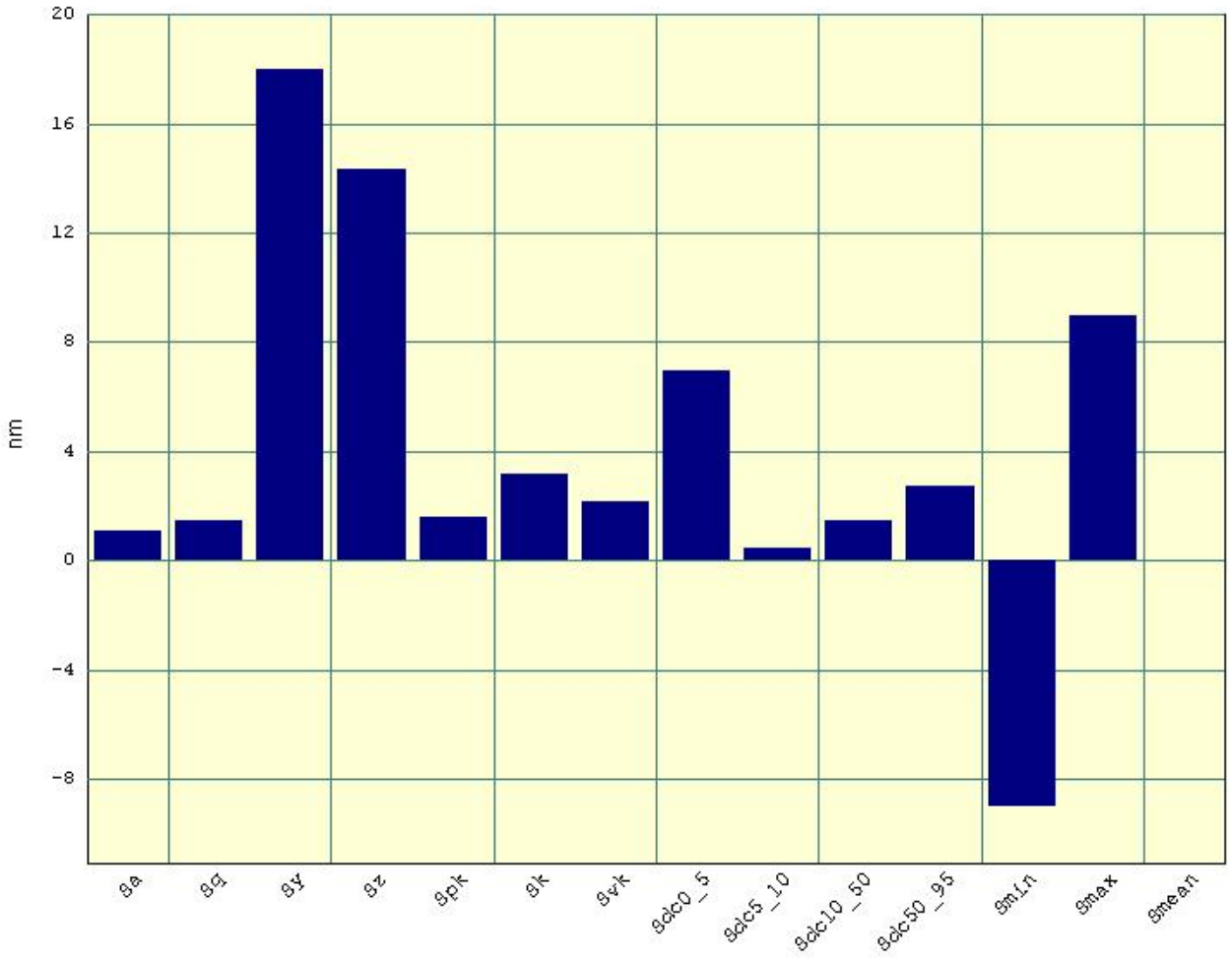
Material:	PEI
Injection Temp	380
Injection Speed	
Injection Pressure	140x15 bar

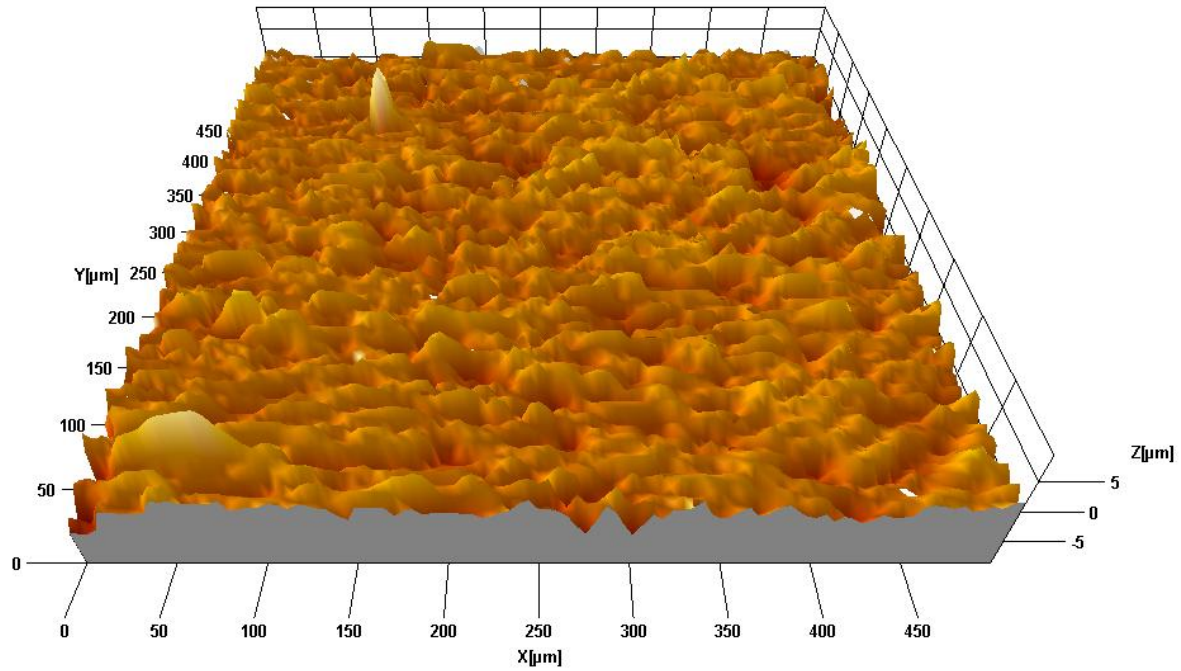
Data

Roughness Data Calculated by SPIP V3.3.9.0
For file: C:\Documents and Settings\Administrator\Desktop\Olivers files\PIG140-1.IGM_FFT
20070614 13_26
1-Xrange 2 Sa 3 Sq 4 Ssk 5 Sku 6 Sy 7 Sz 8 Sds 9 Ssc 10 Smin
11 Smax 12 Smean 13 Sti 14 Sdq 15 Sdr 16 S2A 17 S3A
18 Sbi 19 Sci 20 Svi 21 Spk 22 Sk 23 Svk 24 Std 25 Stdi 26 Srw 27
Srwi 28 Shw 29 Sfd 30 Scl20 31 Str20 32 Scl37 33 Str37
34 Sdc0_5 35 Sdc5_10 36 Sdc10_50 37 Sdc50_95
nm µm µm µm µm 1/um² 1/µm µm µm µm
1/µm % µm² µm² µm µm µm
deg µm µm µm µm µm
µm µm µm
99.0196 1.10 1.46 -0.604 5.39 18.0 14.3 0.0029 0.00685 -
9.03 8.99 -1.82E-8 0.29 391 7.17 2.5E+5 2.68E+5 0.708
1.33 0.154 1.59 3.14 2.14 18.9 0.75 12.1 0.732 16.7 1.83
0.00098 0.333 0.000 0.000 6.93 0.469 1.48 2.71

#C:\Documents and Settings\Administrator\Desktop\Olivers files\PIG140-1.IGM

Sa	**1.10**	**µm**
Sq	1.46	µm
Ssk	-0.604	
Sku	5.39	
Sy	18.0	µm
Sz	14.3	µm
Sds	0.0029	1/um²
Ssc	0.00685	1/µm
Smin	-9.03	µm
Smax	8.99	µm
Smean	-1.82E-8	µm
Sti	0.29	
Sdq	391	1/µm
Sdr	7.17	%
S2A	2.5E+5	µm²
S3A	2.68E+5	µm²
Sbi	0.708	
Sci	1.33	
Svi	0.154	
Spk	1.59	µm
Sk	3.14	µm
Svk	2.14	µm
Std	18.9	deg
Stdi	0.75	
Srw	12.1	µm
Srwi	0.732	
Shw	16.7	µm
Sfd	1.83	
Scl20	0.00098	µm
Str20	0.333	
Scl37	0.000	µm
Str37	0.000	
Sdc0_5	6.93	µm
Sdc5_10	0.469	µm
Sdc10_50	1.48	µm
Sdc50_95	2.71	µm


nm
20
16
12
8
4
0
-4
-8
Sa
Sq
Sy
Sz
Spk
Sk
Svk
Sdc0_5
Sdc5_10
Sdc10_50
Sdc50_95
Smin
Smax
Smean


Y[µm]
450
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
450
X[µm]
Z[µm]
5
0
-5

22.3 Sample no. 3

Material:	PEI
Injection Temp	380
Injection Speed	
Injection Pressure	100x15 bar

Data

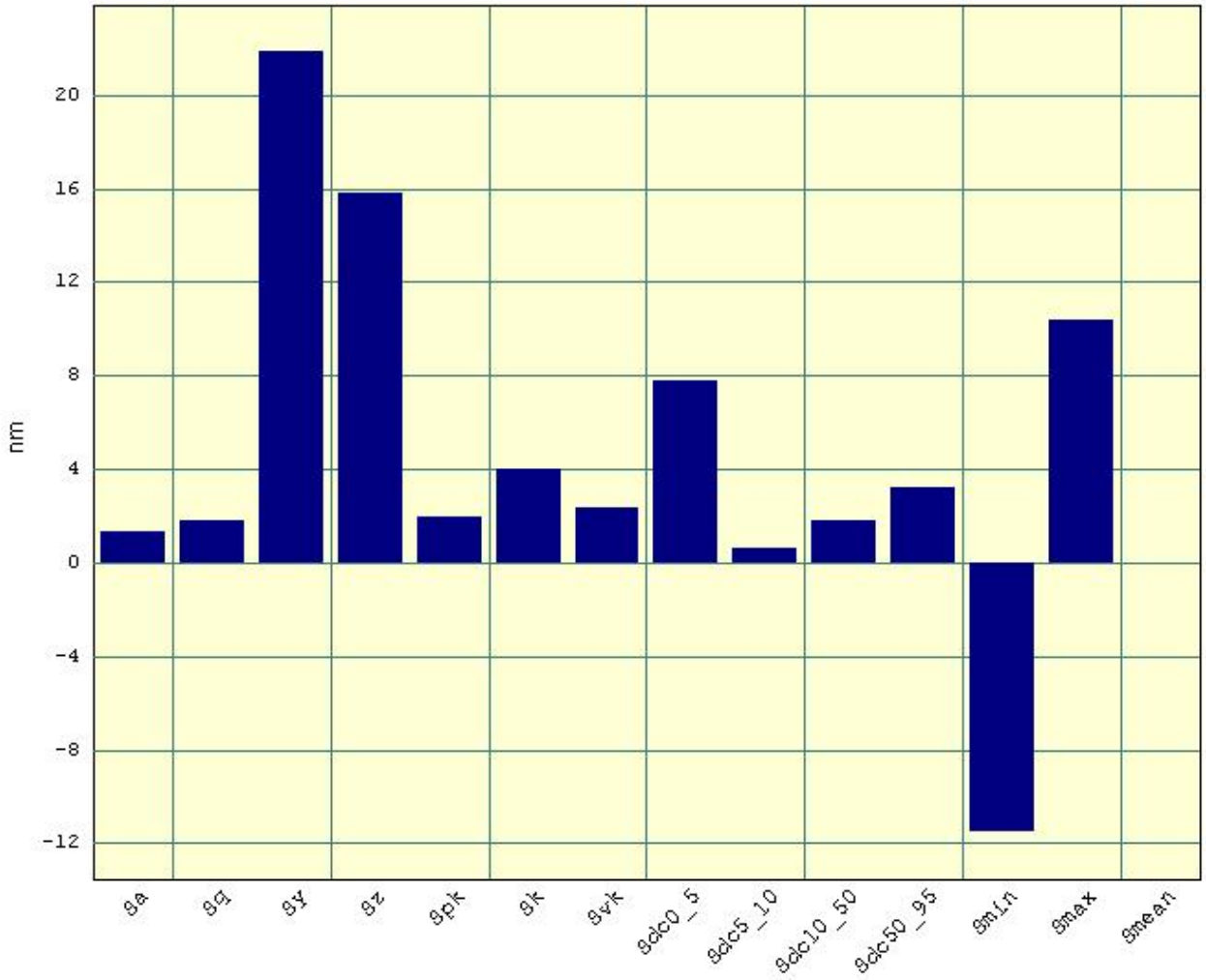
Roughness Data Calculated by SPIP V3.3.9.0
For file: C:\Documents and Settings\Administrator\Desktop\PIG100-1.IGM_FFT
20070612 14_05

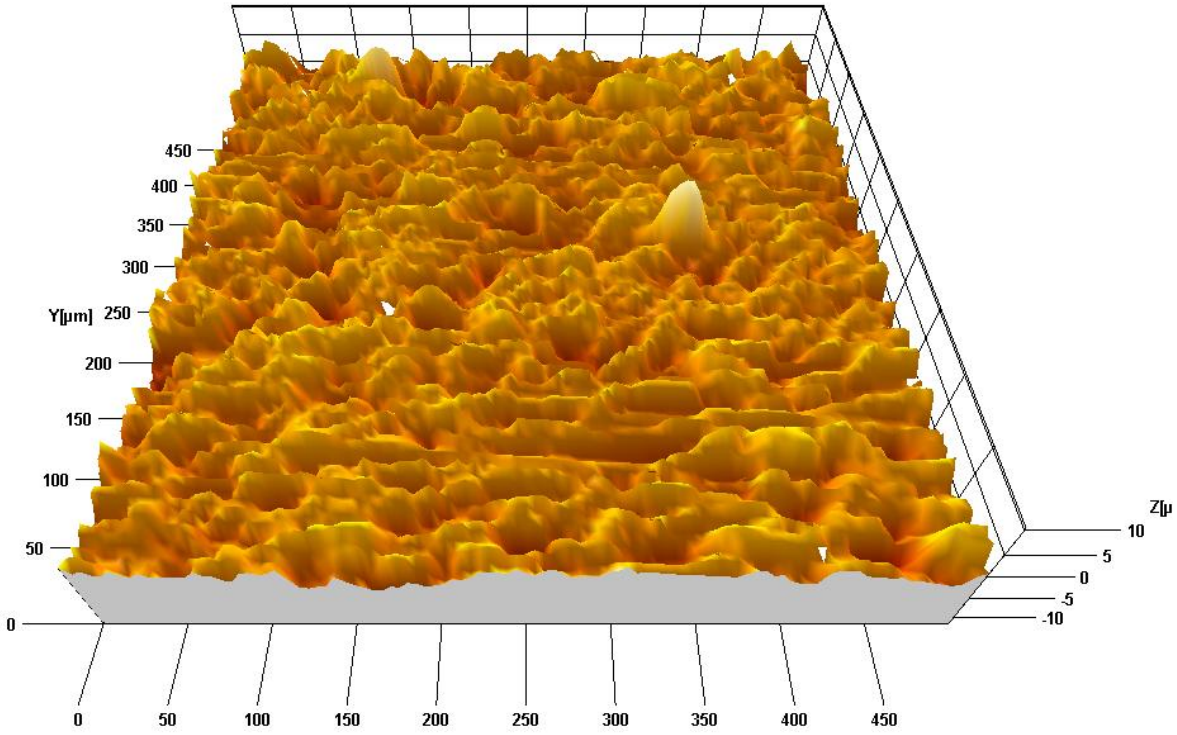
1-Xrange	2 Sa	3 Sq	4 Ssk	5 Sku	6 Sy	7 Sz	8 Sds	9 Ssc	10 Smin	
	11 Smax	12 Smean		13 Sti	14 Sdq	15 Sdr	16 S2A		17 S3A	
	18 Sbi	19 Sci	20 Svi	21 Spk	22 Sk	23 Svk	24 Std	25 Stdi	26 Srw	27
Srwi	28 Shw	29 Sfd	30 Scl20		31 Str20		32 Scl37		33 Str37	
	34 Sdc0_5	35 Sdc5_10		36 Sdc10_50		37 Sdc50_95				
nm	µm	µm		µm	µm	1/um²	1/µm	µm	µm	µm
		1/µm	%	µm²	µm²			µm	µm	µm
	deg		µm		µm		µm			µm
	µm	µm	µm							
99.0196		1.36	1.77	-0.477	4.79	21.8	15.8	0.00244		0.00733
	-11.5	10.4	1.61E-8		0.314	409	7.82	2.5E+5	2.7E+5	0.685
1.38	0.149	2.00	3.99	2.35	9.52	0.676	12.8	0.758	16.7	1.84
	0.00196		0.5	0.00098		0.25	7.79	0.613	1.84	3.20

#C:\Documents and Settings\Administrator\Desktop\PIG100-1.IGM

Sa	**1.36**	**µm**
Sq	1.77	µm
Ssk	-0.477	
Sku	4.79	
Sy	21.8	µm
Sz	15.8	µm
Sds	0.00244	1/um²
Ssc	0.00733	1/µm
Smin	-11.5	µm
Smax	10.4	µm
Smean	1.61E-8	µm
Sti	0.314	
Sdq	409	1/µm
Sdr	7.82	%
S2A	2.5E+5	µm²
S3A	2.7E+5	µm²
Sbi	0.685	
Sci	1.38	
Svi	0.149	
Spk	2.00	µm
Sk	3.99	µm
Svk	2.35	µm

Std	9.52	deg
Stdi	0.676	
Srw	12.8	µm
Srwi	0.758	
Shw	16.7	µm
Sfd	1.84	
Scl20	0.00196	µm
Str20	0.5	
Scl37	0.00098	µm
Str37	0.25	
Sdc0_5	7.79	µm
Sdc5_10	0.613	µm
Sdc10_50	1.84	µm
Sdc50_95	3.20	µm





22.4 Sample no. 4

Material:	PEI
Injection Temp	380
Injection Speed	
Injection Pressure	2400x15 bar

Data
Roughness Data Calculated by SPIP V3.3.9.0
For file: C:\Documents and Settings\Administrator\Desktop\PIG160-1.IGM
20070612 14_32

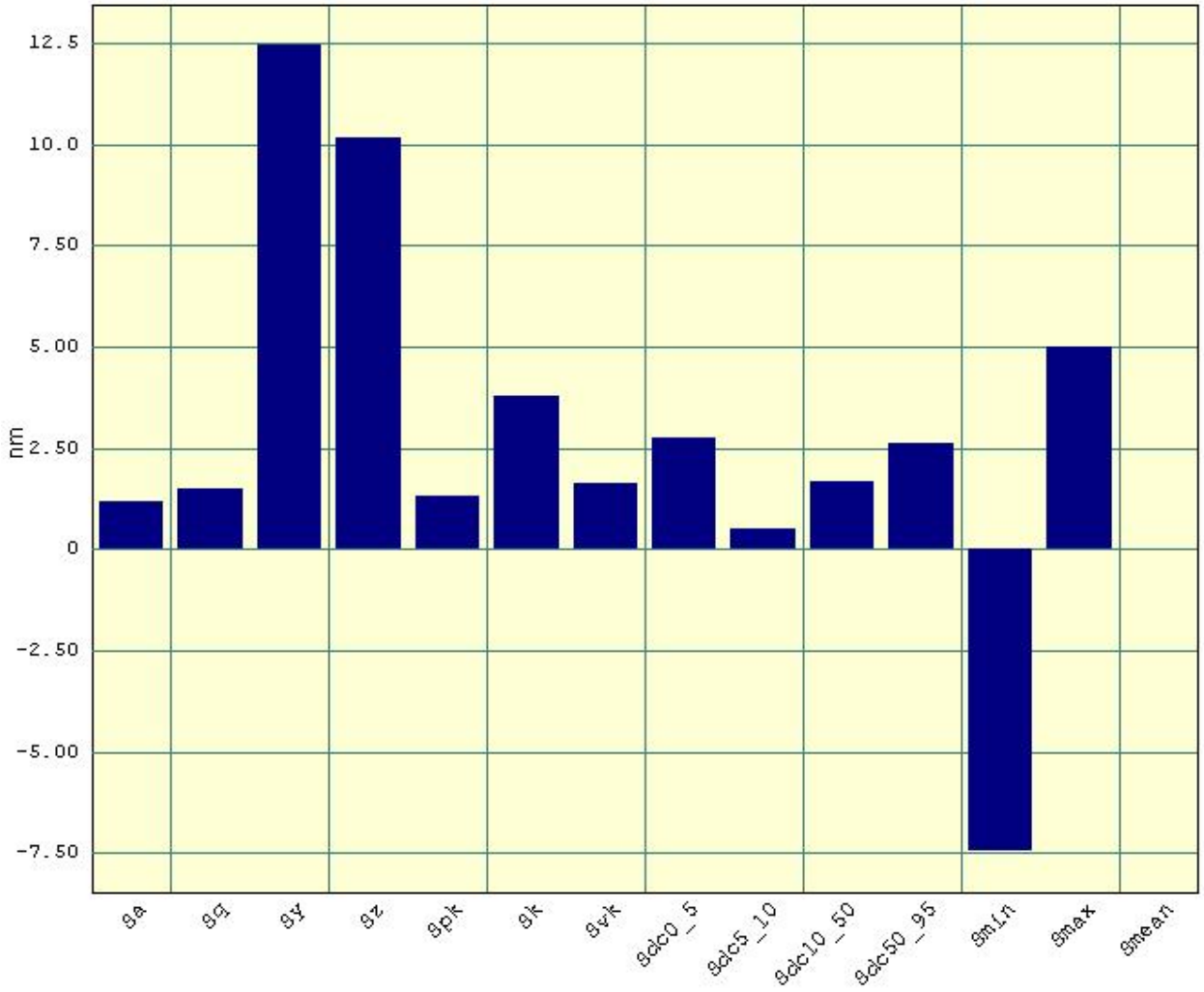
1-Xrange	2 Sa	3 Sq	4 Ssk	5 Sku	6 Sy	7 Sz	8 Sds	9 Ssc	10 Smin
11 Smax	12 Smean	13 Sti	14 Sdq	15 Sdr	16 S2A	17 S3A			
18 Sbi	19 Sci	20 Svi	21 Spk	22 Sk	23 Svk	24 Std	25 Stdi	26 Srw	27 Srwi
28 Shw	29 Sfd	30 Scl20	31 Str20	32 Scl37	33 Str37				
34 Sdc0_5	35 Sdc5_10	36 Sdc10_50	37 Sdc50_95						
nm	µm	µm		µm	µm	1/um²	1/µm	µm	µm	µm
		1/µm	%	µm²	µm²			µm	µm	µm
	deg		µm		µm		µm			µm
	µm	µm	µm							
504950	1.19	1.51	-0.482	3.91	12.4	10.2	0.00249	0.00856	
	-7.42	5.02	-0.000509	0.37	356	6.06	93416	99072	0.661
1.46	0.134	1.28	3.77	1.63	71.4	0.856	120	0.5	28.1	2.32
15.0	0.366	10.00	0.244	2.74	0.515	1.68	2.64	#C:\Documents and		

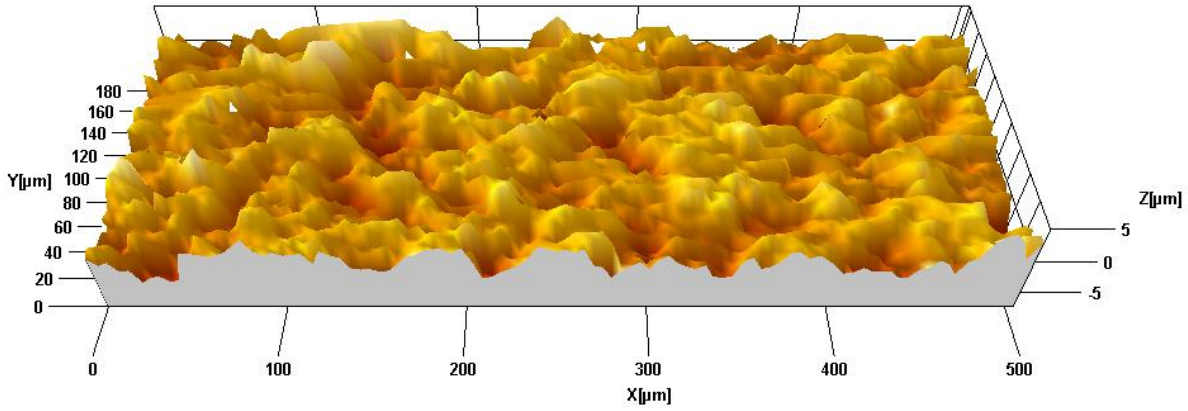
Settings\Administrator\Desktop\PIG160-1.IGM

Sa 1.19 µm

Sq	1.51	µm
Ssk	-0.482	
Sku	3.91	
Sy	12.4	µm
Sz	10.2	µm
Sds	0.00249	1/um²
Ssc	0.00856	1/µm
Smin	-7.42	µm
Smax	5.02	µm
Smean	-0.000509	µm
Sti	0.37	
Sdq	356	1/µm
Sdr	6.06	%
S2A	93416	µm²
S3A	99072	µm²
Sbi	0.661	
Sci	1.46	
Svi	0.134	
Spk	1.28	µm
Sk	3.77	µm
Svk	1.63	µm
Std	71.4	deg
Stdi	0.856	
Srw	120	µm
Srwi	0.5	
Shw	28.1	µm
Sfd	2.32	
Scl20	15.0	µm
Str20	0.366	
Scl37	10.00	µm
Str37	0.244	
Sdc0_5	2.74	µm
Sdc5_10	0.515	µm
Sdc10_50	1.68	µm

Sdc50_95 2.64
µm





22.5 Sample no. 5

Material:	PS
Injection Temp	??
Injection Speed	??
Injection Pressure	??

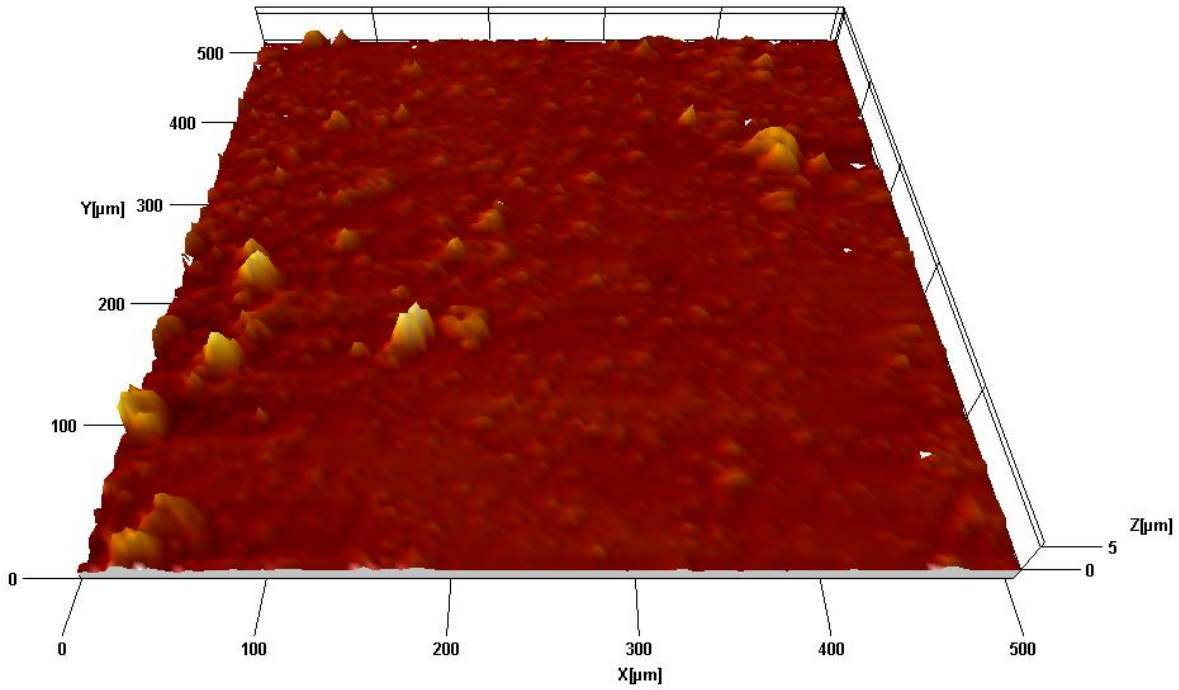
Data

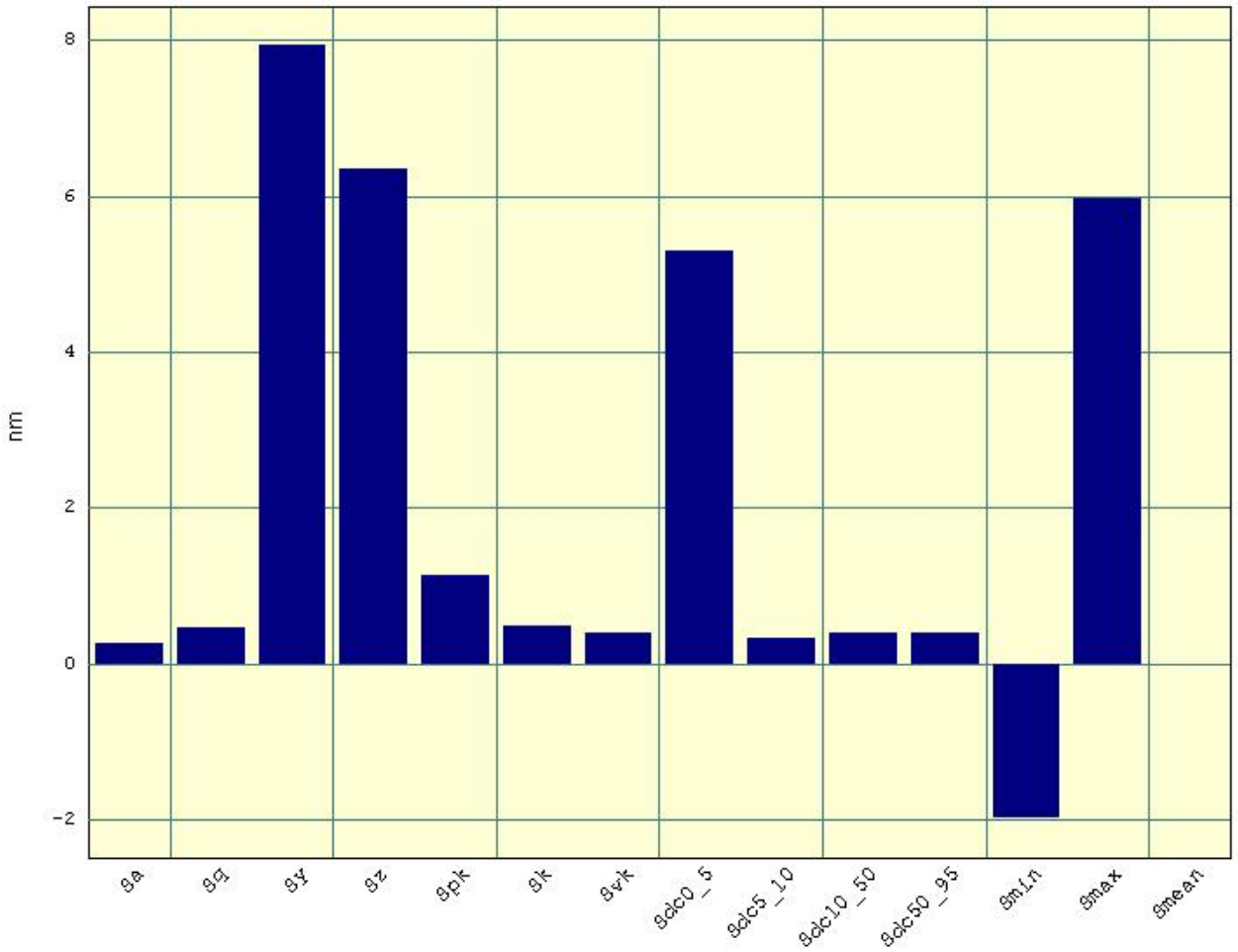
Roughness Data Calculated by SPIP V3.3.9.0
For file: C:\Documents and Settings\Administrator\Desktop\PS1.IGM_FFT
20070612 14_35

1-Xrange	2 Sa	3 Sq	4 Ssk	5 Sku	6 Sy	7 Sz	8 Sds	9 Ssc	10 Smin
11 Smax	12 Smean	13 Sti	14 Sdq	15 Sdr	16 S2A	17 S3A			
18 Sbi	19 Sci	20 Svi	21 Spk	22 Sk	23 Svk	24 Std	25 Stdi	26 Srw	27 Srwi
28 Shw	29 Sfd	30 Scl20	31 Str20	32 Scl37	33 Str37				
34 Sdc0_5	35 Sdc5_10	36 Sdc10_50	37 Sdc50_95						
nm	µm	µm		µm	µm	1/um²	1/µm	µm	µm	µm
	1/µm	%	µm²	µm²				µm	µm	µm
	deg		µm		µm		µm			µm
	µm	µm	µm							
99.0196	0.258	0.466	3.71	30.4	7.94	6.36	0.00345	0.00311		
	-1.97	5.97	-6.22E-10	0.48	118	0.687	2.5E+5	2.52E+5		
	0.71	1.47	0.0802	1.14	0.491	0.398	7.31	0.721	12.2	0.881
18.5	1.91	0.00196	0.667	0.00098	0.333	5.31	0.334	0.398		
	0.398	#C:\Documents and Settings\Administrator\Desktop\PS1.IGM								

Sa 0.258 µm

Sq	0.466	µm
Ssk	3.71	
Sku	30.4	
Sy	7.94	µm
Sz	6.36	µm
Sds	0.00345	1/um²
Ssc	0.00311	1/µm
Smin	-1.97	µm
Smax	5.97	µm
Smean	-6.22E-10	µm
Sti	0.48	
Sdq	118	1/µm
Sdr	0.687	%
S2A	2.5E+5	µm²
S3A	2.52E+5	µm²
Sbi	0.71	
Sci	1.47	
Svi	0.0802	
Spk	1.14	µm
Sk	0.491	µm
Svk	0.398	µm
Std	7.31	deg
Stdi	0.721	
Srw	12.2	µm
Srwi	0.881	
Shw	18.5	µm
Sfd	1.91	
Scl20	0.00196	µm
Str20	0.667	
Scl37	0.00098	µm
Str37	0.333	
Sdc0_5	5.31	µm
Sdc5_10	0.334	µm
Sdc10_50	0.398	µm
Sdc50_95	0.398	µm


500
400
Y[µm] 300
200
100
0
0
100
200
300
400
500
X[µm]
Z[µm]
5
0


nm
8
6
4
2
0
-2
Sa
Sq
Sy
Sz
Spk
Sk
Svk
Sdc0_5
Sdc5_10
Sdc10_50
Sdc50_95
Smin
Smax
Smean

Sample no. 6

Material:	Polystyren with glassfibers
Injection Temp	??
Injection Speed	??
Injection Pressure	??

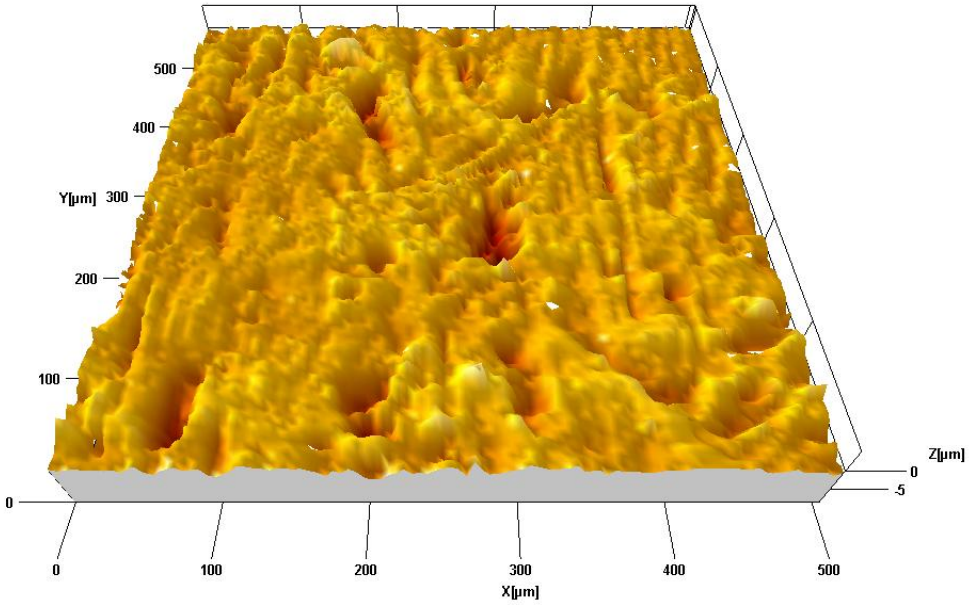
Data

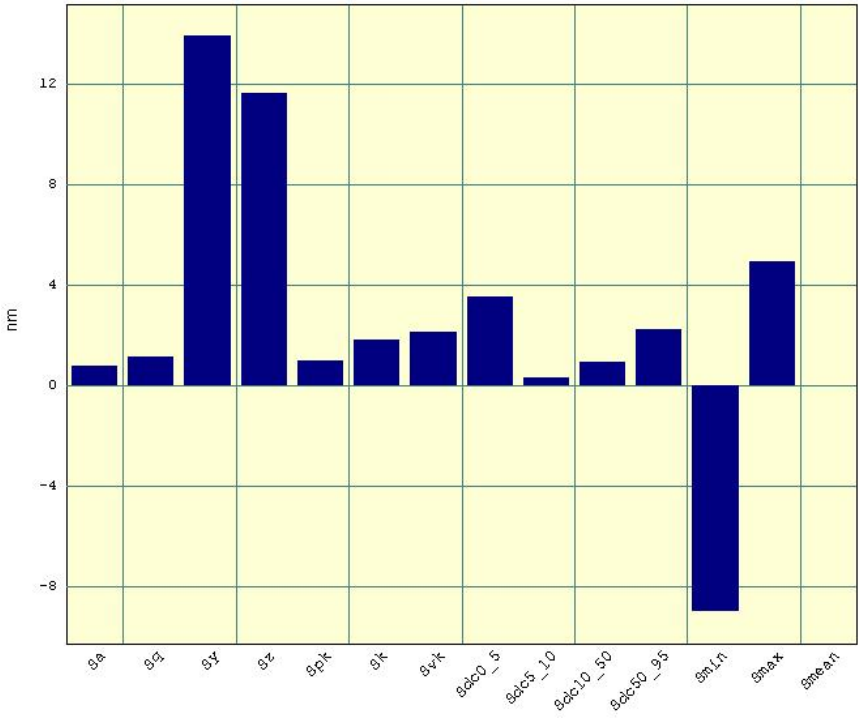
Roughness Data Calculated by SPIP V3.3.9.0
For file: C:\Documents and Settings\Administrator\Desktop\PSG1.IGM_FFT
20070612 14_40

1-Xrange	2 Sa	3 Sq	4 Ssk	5 Sku	6 Sy	7 Sz	8 Sds	9 Ssc	10 Smin
11 Smax	12 Smean	13 Sti	14 Sdq	15 Sdr	16 S2A	17 S3A			
18 Sbi	19 Sci	20 Svi	21 Spk	22 Sk	23 Svk	24 Std	25 Stdi	26 Srw	27 Srwi
28 Shw	29 Sfd	30 Scl20	31 Str20	32 Scl37	33 Str37				
34 Sdc0_5	35 Sdc5_10	36 Sdc10_50	37 Sdc50_95						
nm	µm	µm		µm	µm	1/um²	1/µm	µm	µm	µm
	1/µm	%	µm²	µm²				µm	µm	µm
	deg		µm		µm		µm			µm
	µm	µm	µm							
99.0196	0.781	1.14	-1.69	9.15	13.9	11.6	0.00282	0.00443		
	-8.96	4.95	-7.14E-9	0.601	237	2.71	2.5E+5	2.57E+5		
	0.79	1.13	0.2	0.996	1.82	2.13	178	0.611	500	1.36
18.5	1.93	0.00196	0.333	0.00139	0.236	3.51	0.334	0.948		
2.23	#C:\Documents and Settings\Administrator\Desktop\PSG1.IGM									

Sa	0.781	µm
Sq	1.14	µm
Ssk	-1.69	
Sku	9.15	
Sy	13.9	µm
Sz	11.6	µm
Sds	0.00282	1/um²
Ssc	0.00443	1/µm
Smin	-8.96	µm
Smax	4.95	µm
Smean	-7.14E-9	µm
Sti	0.601	
Sdq	237	1/µm
Sdr	2.71	%
S2A	2.5E+5	µm²
S3A	2.57E+5	µm²
Sbi	0.79	
Sci	1.13	
Svi	0.2	
Spk	0.996	µm
Sk	1.82	µm
Svk	2.13	µm
Std	178	deg

Stdi	0.611	
Srw	500	µm
Srwi	1.36	
Shw	18.5	µm
Sfd	1.93	
Scl20	0.00196	µm
Str20	0.333	
Scl37	0.00139	µm
Str37	0.236	
Sdc0_5	3.51	µm
Sdc5_10	0.334	µm
Sdc10_50	0.948	µm
Sdc50_95	2.23	µm


500
400
Y[µm] 300
200
100
0
0
100
200
300
400
500
X[µm]
Z[µm]
0
-5


12
8
4
0
-4
-8
nm
Sa
Sq
Sy
Sz
Spk
Sk
Svk
Sdc0_5
Sdc5_10
Sdc10_50
Sdc50_95
Smin
Smax
Smean

Software used

Version 3.3.9.0, Apr 5 2005

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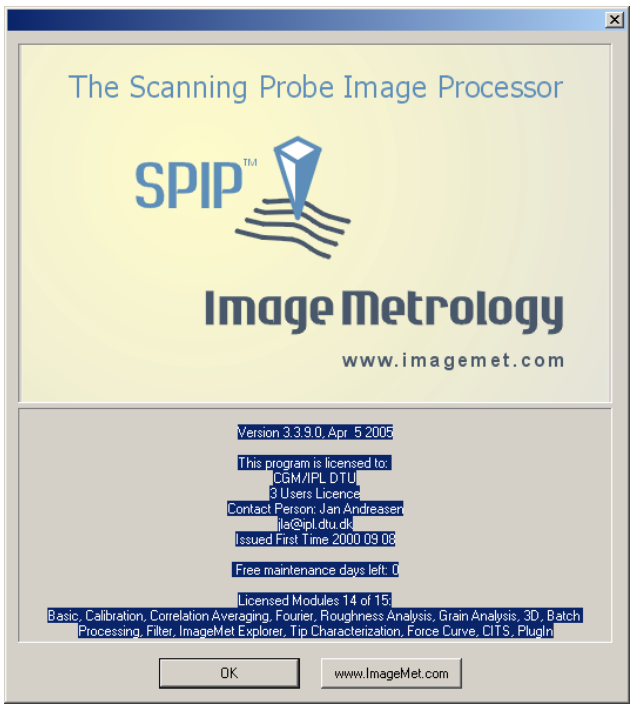
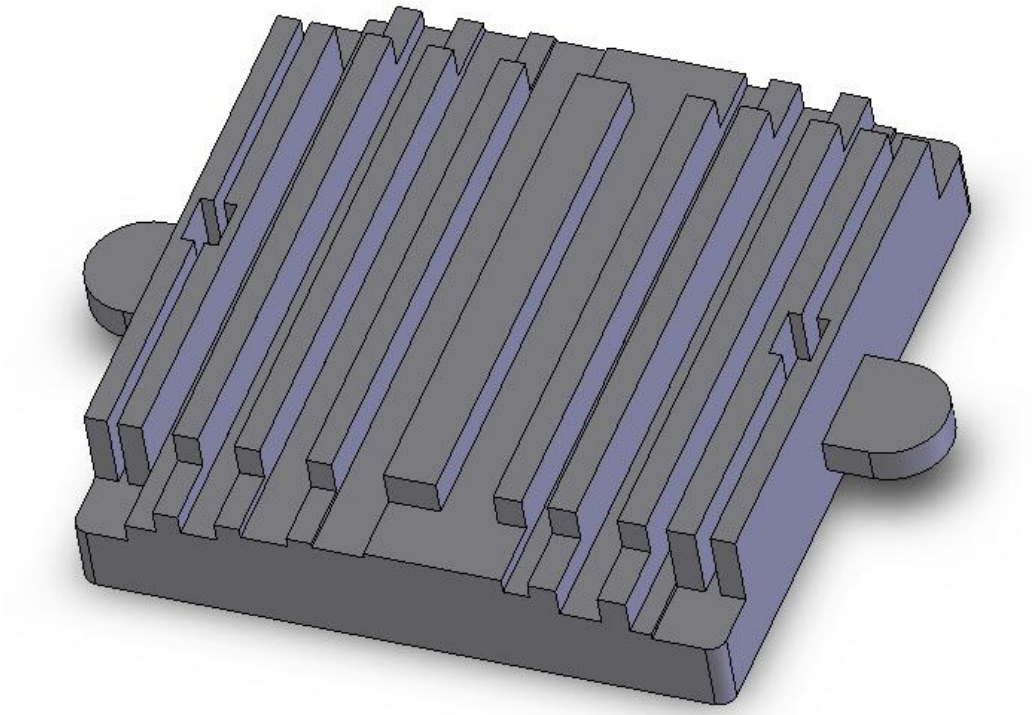
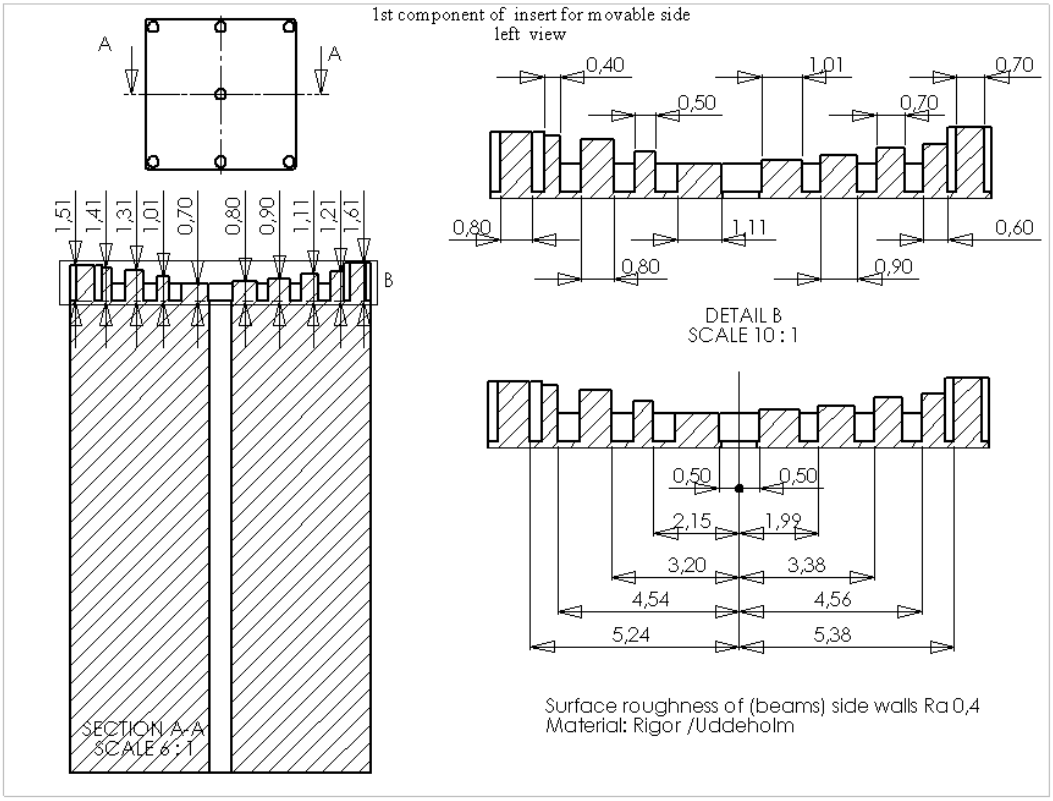
Basic, Calibration, Correlation Averaging, Fourier, Roughness Analysis, Grain Analysis, 3D, Batch Processing, Filter, ImageMet Explorer, Tip Characterization, Force Curve, CITS, PlugIn

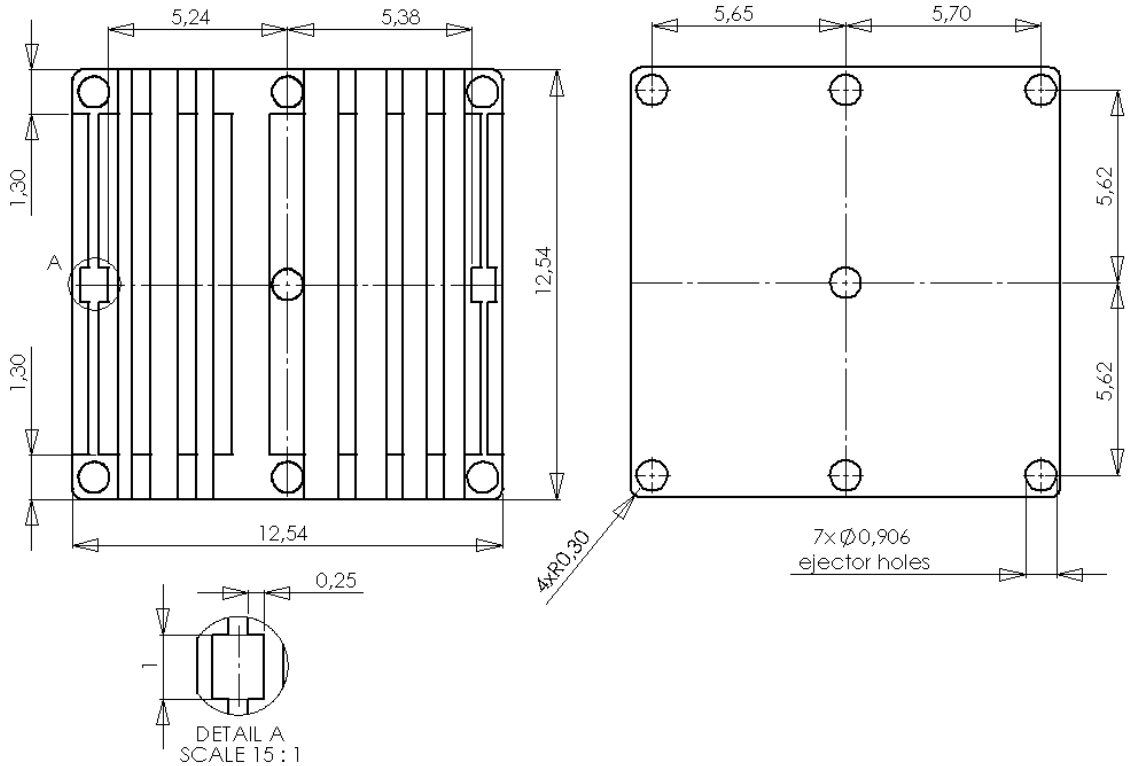


23 Test Specimen geometry

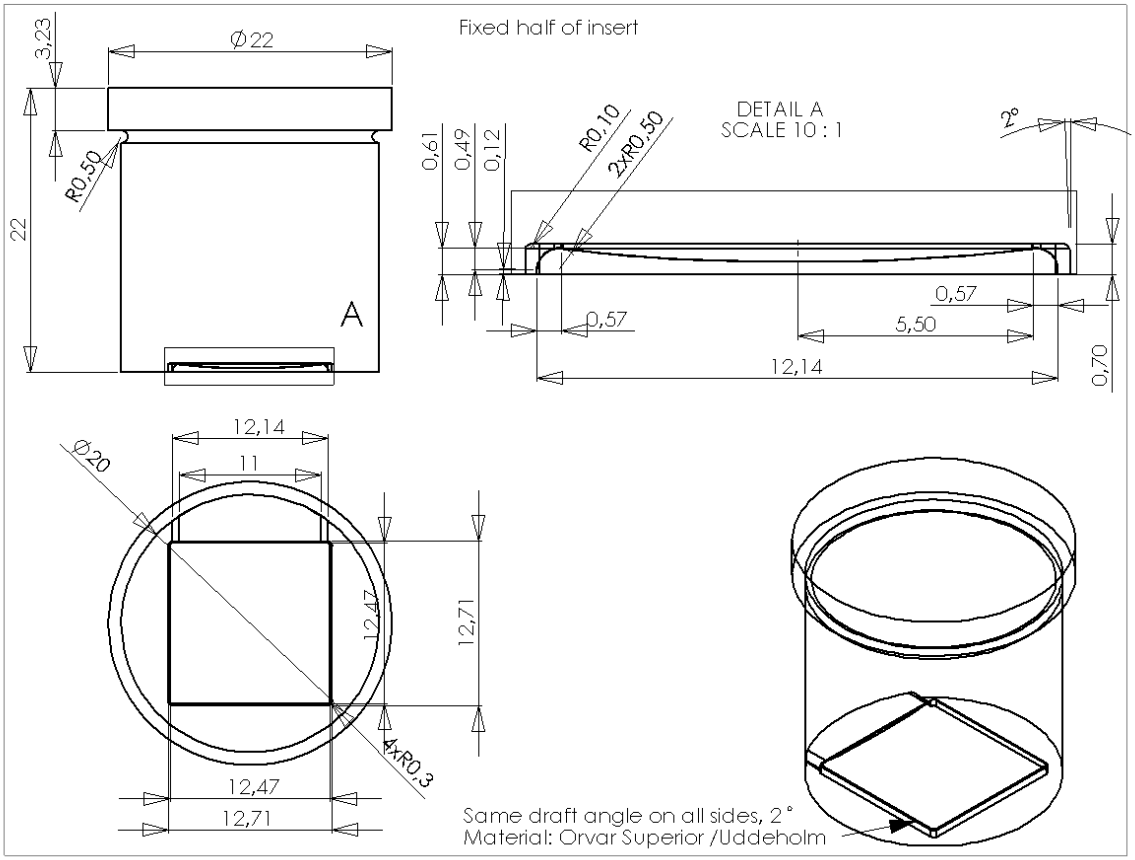


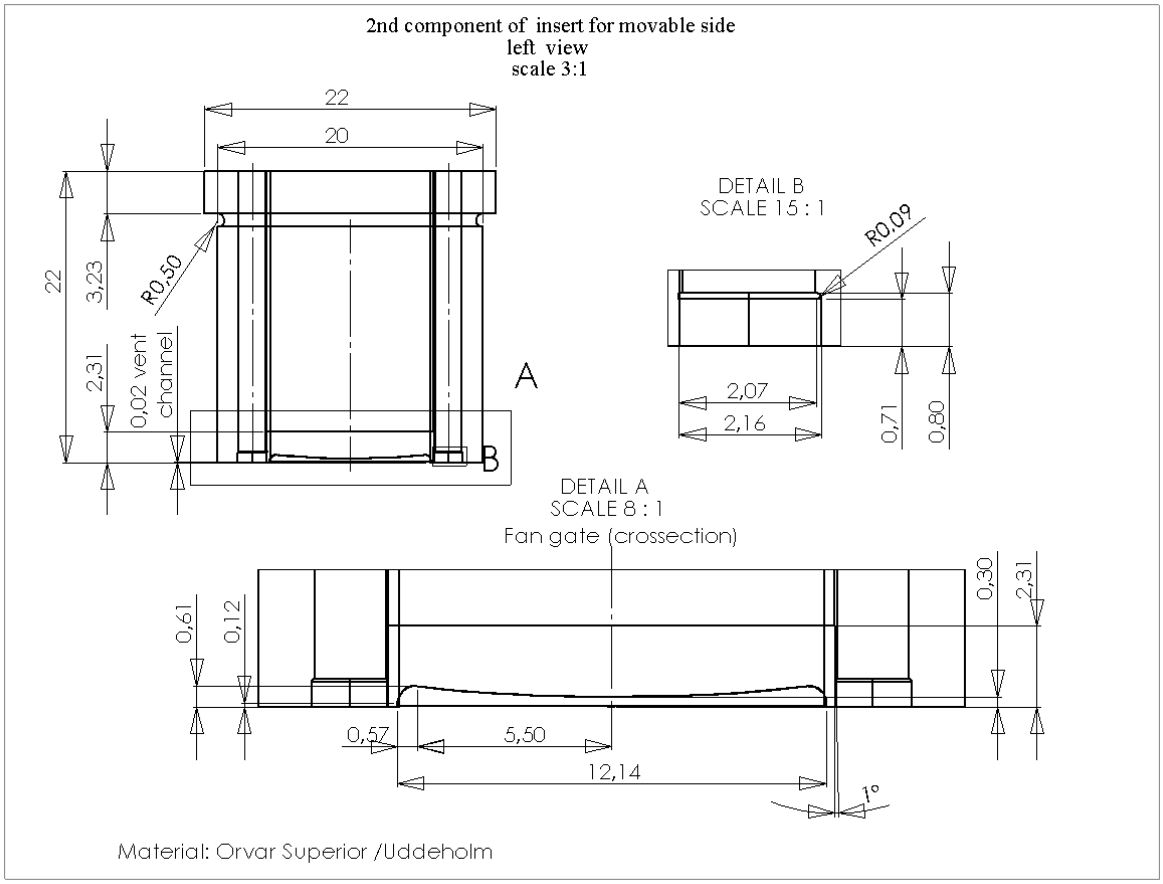


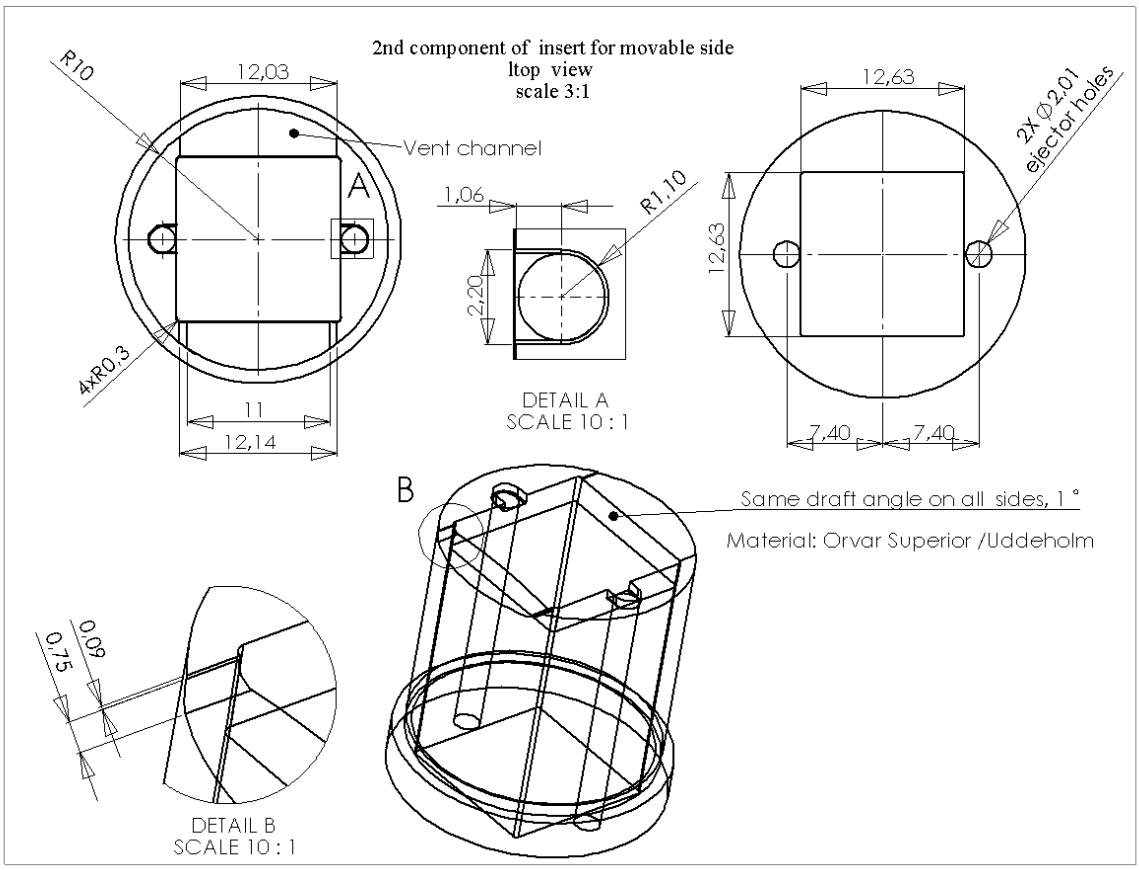
1st component of insert for movable side Material: Rigor /Uddeholm
top / back view
scale 8:1

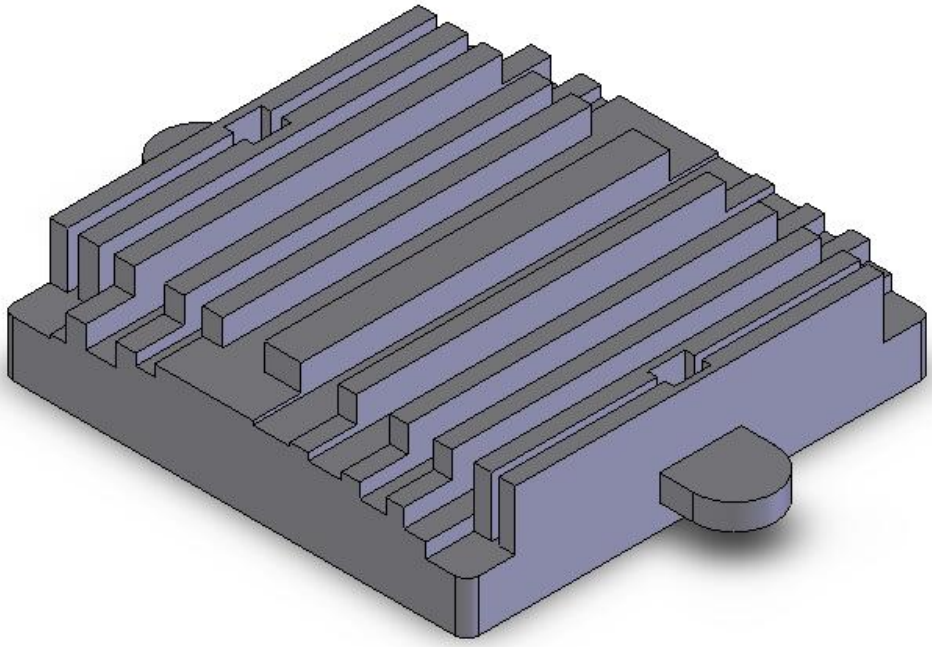


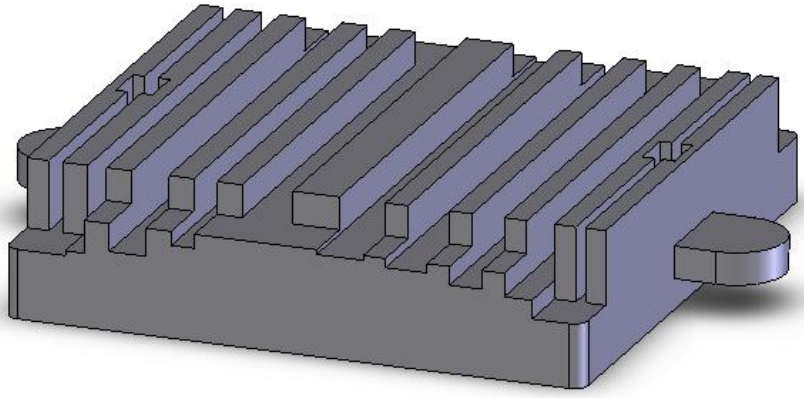
Reinforcement, symmetric




2nd component of insert for movable side
left view
scale 3:1
22
20
22
3,23
2,31
0,02 vent channel
R0,50
A
B
DETAIL B
SCALE 15 : 1
R0,09
2,07
2,16
0,71
0,80
DETAIL A
SCALE 8 : 1
Fan gate (crossection)
0,61
0,12
0,30
2,31
0,57
5,50
12,14
1°
Material: Orvar Superior /Uddeholm


2nd component of insert for movable side
ltop view
scale 3:1
R10
12,03
Vent channel
A
4xR0.3
11
12,14
1,06
R1,10
2,20
DETAIL A
SCALE 10 : 1
12,63
2X Ø2,01 ejector holes
12,63
7,40
7,40
B
Same draft angle on all sides, 1 °
Material: Orvar Superior /Uddeholm
0,09
0,75
DETAIL B
SCALE 10 : 1





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B. Sha, S. Dimov, C. Griffiths and M. S. Packianather
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E. Kristofer Gamstedta,*, Lars A. Berglund a, Ton Peijs b
aDivision of Polymer Engineering, LuleaÊ University of Technology, SE-971 87 LuleaÊ, Sweden
bCentre for Polymers and Composites, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

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ERIC LAFRANCHE, PATRICIA KRAWCZAK
Ecole des Mines de Douai, Polymers and Composites Technology Department, 941 rue Charles Bourseul,
BP 838, F-59508 Douai, France

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Division of Materials Technology, School of Energy and Materials, King Mongkut's University of Technology
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B. Mlekusch*
Institute for Designing Plastics and Composite Materials, University of Leoben, Austria

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